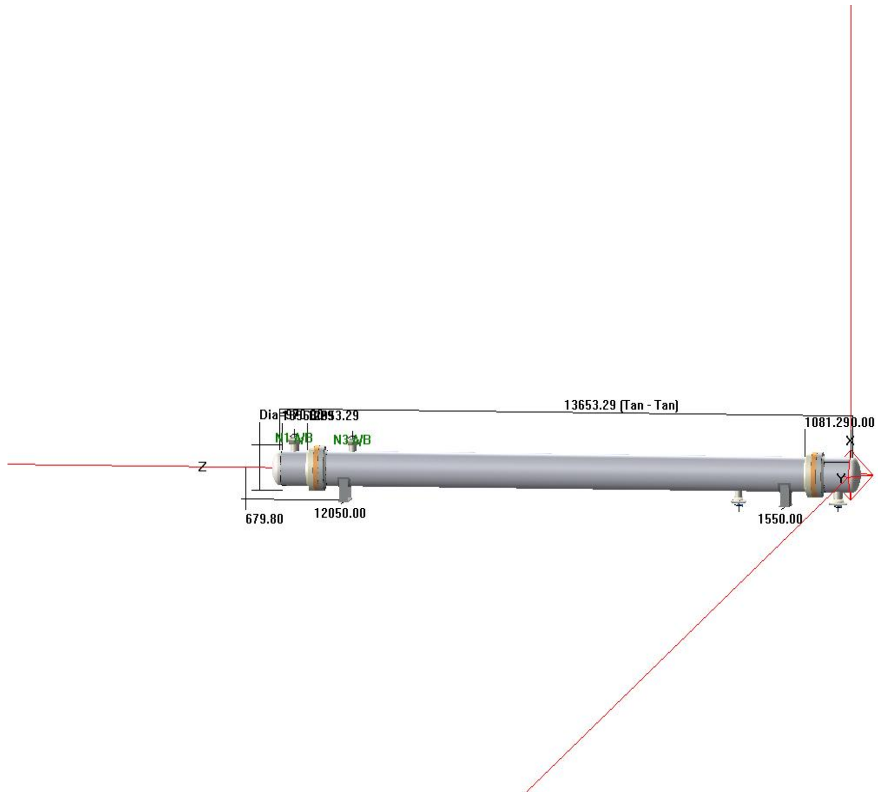
DESCON ENGINEERING LIMITED

FZE Humriyah



COMPRESS Pressure Vessel Design Calculations

Item. :	Glycol Reboiler and stripping Gas Heater
Vessel Tag No. :	607-E-1105/2105/3105
Contractor / Client. :	ADMA
Proposal Number. :	11924
Designer:	IUH
Date:	Thursday, October 30, 2014

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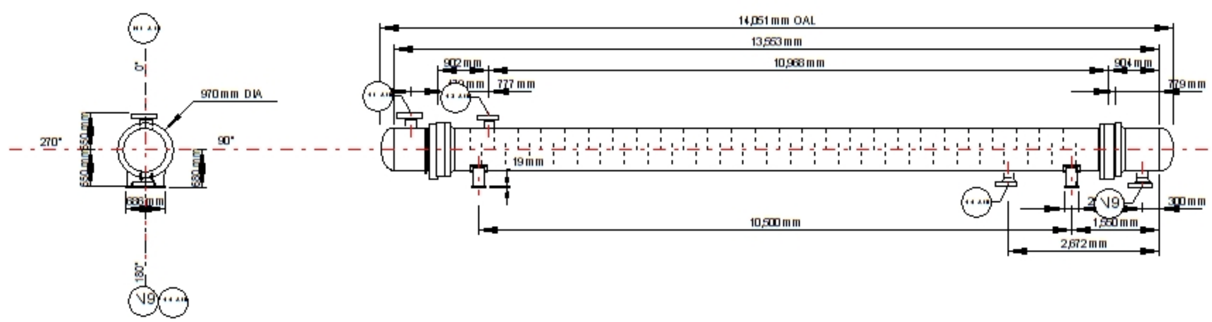


DESIGN DATA	SHELL	TUBE
Design Pressure	7,700.01 kPa	7,700.01 kPa
Vacuum Pressure	N/A	N/A
Test Pressure (Shop)	10,350.09 kPa	10,304.84 kPa
Design Temperature	85 °C	85 °C
MDMT	-29 °C	-29 °C
Corrosion Allowance	3 mm	0 mm
Number of Passes	1	1
Radiography	RT1	RT1
PWHT	None	None

Estimated Weights

Dry: 16,910 kg Wet: 16,910 kg
Bundle: 7,151 kg
Weight at left saddle: 8,445 kg (Oper), 10,628 kg (Test)
Weight at right saddle: 8,466 kg (Oper), 10,668 kg (Test)

Materials

Channel: SA-516 70
Shell: SA-516 70
Tubesheets: SA-350 LF2 Cl 1
Baffles: SA-36
Tubes: SA-179 Smls. Tube

Tubes (537) 19.05 mm OD x 2.77 mm x 12,000 mm LONG
Tube Pitch = 25.4 mm Square (90°)
Tube Surface Area = 386 m²
Gaskets:
Flexitallic Spiral Wound CG 304 S.S.

NOZZLE SCHEDULE

MARK	NOZZLE	SIZE & SCH	FLANGE	MARK	NOZZLE	SIZE & SCH	FLANGE
N9	8" Two Nozzles	NPS 8 Sch 80 (XS) DN 2	NPS 8 WN Class 600				
N4 A/B	6" Two Nozzles	NPS 6 Sch 80 (XS) DN 1	NPS 6 WN Class 600				
N3 A/B	6" Two Nozzles	NPS 6 Sch 80 (XS) DN 1	NPS 6 WN Class 600				
N1 A/B	8" Two Nozzles	NPS 8 Sch 80 (XS) DN 2	NPS 8 WN Class 600				

REVISIONS

REV	DATE	DESCRIPTION
0	10/30/2014	FOR APPROVAL

ABC Fabricators Inc.
2600 Washington Blvd.
Dallas, TX, 75204

ASME VIII-1 2013 Edition	TEMA Type: BEM
Size: 28-472.4409	TEMA Class: R
DWN BY:	General Arrangement
CHK BY:	
DATE:	DWG NO. 145685-1 — Rev 0

E-2302 C.CW7

Deficiencies Summary

Deficiencies for 6" Two Nozzles (N3 A/B)
Nozzle weight has been increased to account for the additional 1 nozzles specified for costing. This weight is assumed to act at the location of this nozzle.

Deficiencies for 6" Two Nozzles (N4 A/B)
Nozzle weight has been increased to account for the additional 1 nozzles specified for costing. This weight is assumed to act at the location of this nozzle.

Deficiencies for 8" Two Nozzles (N1 A/B)
Nozzle weight has been increased to account for the additional 1 nozzles specified for costing. This weight is assumed to act at the location of this nozzle.

Deficiencies for Heat Exchanger
TEMA A.23: Tube longitudinal compressive stress is excessive (Operating).
ASME VIII-1, Table A-2 note (7): Ratio of tube OD/ID requires that factor fr be determined by test.

Warnings Summary

Warnings for 6" Two Nozzles (N3 A/B)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)
Part of the pad width is beyond the limits of reinforcement. (warning)

Warnings for 6" Two Nozzles (N4 A/B)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)
Part of the pad width is beyond the limits of reinforcement. (warning)

Warnings for 8" Two Nozzles (N1 A/B)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)

Warnings for 8" Two Nozzles (N9)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)

Warnings for Front Head
UCS-79: The extreme fiber elongation exceeds 5 percent and the thickness exceeds 16 mm;. Heat treatment per UCS-56 is required if fabricated by cold forming. (warning)

Warnings for Heat Exchanger
UG-6(c): Tubesheet forging must meet the requirements of UG-6(c). (warning)

Warnings for Rear Channel Head
UCS-79: The extreme fiber elongation exceeds 5 percent and the thickness exceeds 16 mm;. Heat treatment per UCS-56 is required if fabricated by cold forming. (warning)

Warnings for Shell Side Flange (front)
Jawad and Farr Guidebook, 4.3.1.3: To prevent gasket crushout a different gasket material should be used. As an alternative (space permitting) the gasket width could be increased to 14.04 mm. (warning)
UG-6(c): Forging must meet the requirements of UG-6(c). (warning)
UG-6(c)(1): Forging must be subject to one of the austenitizing heat treatments permitted by the specification. (warning)

Warnings for Shell Side Flange (rear)
Jawad and Farr Guidebook, 4.3.1.3: To prevent gasket crushout a different gasket material should be used. As an alternative (space permitting) the gasket width could be increased to 14.04 mm. (warning)
UG-6(c): Forging must meet the requirements of UG-6(c). (warning)
UG-6(c)(1): Forging must be subject to one of the austenitizing heat treatments permitted by the specification.

(warning)

Warnings for Tube Side Flange (front)
Jawad and Farr Guidebook, 4.3.1.3: To prevent gasket crushout a different gasket material should be used. As an alternative (space permitting) the gasket width could be increased to 14.04 mm. (warning)
UG-6(c): Forging must meet the requirements of UG-6(c). (warning)
UG-6(c)(1): Forging must be subject to one of the austenitizing heat treatments permitted by the specification. (warning)

Warnings for Tube Side Flange (rear)
Jawad and Farr Guidebook, 4.3.1.3: To prevent gasket crushout a different gasket material should be used. As an alternative (space permitting) the gasket width could be increased to 14.04 mm. (warning)
UG-6(c): Forging must meet the requirements of UG-6(c). (warning)
UG-6(c)(1): Forging must be subject to one of the austenitizing heat treatments permitted by the specification. (warning)

Nozzle Schedule

Nozzle mark	Service	Size	Materials		Impact Tested	Normalized	Fine Grain	Flange	Blind
N1 A/B	8" Two Nozzles	NPS 8 Sch 80 (XS) DN 200	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 8 Class 600 WN A105	No
			Pad	SA-516 70	No	No	No		
N3 A/B	6" Two Nozzles	NPS 6 Sch 80 (XS) DN 150	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 6 Class 600 WN A105	No
			Pad	SA-516 70	No	No	No		
N4 A/B	6" Two Nozzles	NPS 6 Sch 80 (XS) DN 150	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 6 Class 600 WN A105	No
			Pad	SA-516 70	No	No	No		
N9	8" Two Nozzles	NPS 8 Sch 80 (XS) DN 200	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 8 Class 600 WN A105	No
			Pad	SA-516 70	No	No	No		

Nozzle Summary

Nozzle mark	OD (mm)	t_n (mm)	Req t_n (mm)	A_1?	A_2?	Shell			Reinforcement Pad		Corr (mm)	A_a/A_r (%)
						Nom t (mm)	Design t (mm)	User t (mm)	Width (mm)	t_{pad} (mm)		
N1 A/B	219.08	12.7	11.61	Yes	Yes	25	23.89		75	25	3	100.0
N3 A/B	168.27	10.97	10.54	Yes	Yes	25	24.2		75	20	3	100.0
N4 A/B	168.27	10.97	10.54	Yes	Yes	25	24.2		75	20	3	100.0
N9	219.08	12.7	11.61	Yes	Yes	25	23.89		75	25	3	100.0

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

Pressure Summary

Pressure Summary for Tube side chamber

<table>
<tr><th>Identifier</th><th>P Design (kPa)</th><th>T Design (°C)</th><th>MAWP (kPa)</th><th>MAP (kPa)</th><th>MAEP (kPa)</th><th>T_e external (°C)</th><th>MDMT (°C)</th><th colspan="2">MDMT Exemption</th><th>Impact Tested</th></tr>
<tr><td>Front Head</td><td>7,700.01</td><td>85</td><td>8,252.97</td><td>9,398.41</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 1</td><td>No</td></tr>
<tr><td>Straight Flange on Front Head</td><td>7,700.01</td><td>85</td><td>7,926.8</td><td>9,088.91</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 2</td><td>No</td></tr>
<tr><td>Front Channel</td><td>7,700.01</td><td>85</td><td>8,290.65</td><td>9,452.05</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 3</td><td>No</td></tr>
<tr><td>Tubesheet</td><td>7,700.01</td><td>85</td><td>8,970.11</td><td>9,665.9</td><td>17,365.01</td><td>85</td><td>-49</td><td colspan="2">Note 4</td><td>No</td></tr>
<tr><td>Rear Tubesheet</td><td>7,700.01</td><td>85</td><td>8,970.11</td><td>9,665.9</td><td>17,365.01</td><td>85</td><td>-49</td><td colspan="2">Note 4</td><td>No</td></tr>
<tr><td>Rear Channel</td><td>7,700.01</td><td>85</td><td>8,290.65</td><td>9,452.05</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 3</td><td>No</td></tr>
<tr><td>Straight Flange on Rear Channel Head</td><td>7,700.01</td><td>85</td><td>7,926.8</td><td>9,088.91</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 2</td><td>No</td></tr>
<tr><td>Rear Channel Head</td><td>7,700.01</td><td>85</td><td>8,252.97</td><td>9,398.41</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 5</td><td>No</td></tr>
<tr><td>Tubes</td><td>7,700.01</td><td>85</td><td>26,176.67</td><td>26,176.67</td><td>18,298.14</td><td>85</td><td>-105</td><td colspan="2">Note 6</td><td>No</td></tr>
<tr><td>Tube Side Flange (front)</td><td>7,700.01</td><td>85</td><td>7,961.61</td><td>7,961.61</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 7</td><td>No</td></tr>
<tr><td>Tube Side Flange (front) - Flange Hub</td><td>7,700.01</td><td>85</td><td>8,290.65</td><td>9,452.05</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 3</td><td>No</td></tr>
<tr><td>Tube Side Flange (rear)</td><td>7,700.01</td><td>85</td><td>7,961.61</td><td>7,961.61</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 7</td><td>No</td></tr>
<tr><td>Tube Side Flange (rear) - Flange Hub</td><td>7,700.01</td><td>85</td><td>8,290.65</td><td>9,452.05</td><td>N/A</td><td>85</td><td>-29</td><td colspan="2">Note 3</td><td>No</td></tr>
<tr><td rowspan="2">8" Two Nozzles (N1 A/B)</td><td rowspan="2">7,700.01</td><td rowspan="2">85</td><td rowspan="2">8,116.25</td><td rowspan="2">9,048.06</td><td rowspan="2">N/A</td><td rowspan="2">85</td><td rowspan="2">-29</td><td>Nozzle</td><td>Note 8</td><td>No</td></tr>
<tr><td>Pad</td><td>Note 9</td><td>No</td></tr>
<tr><td rowspan="2">8" Two Nozzles (N9)</td><td rowspan="2">7,700.01</td><td rowspan="2">85</td><td rowspan="2">8,116.25</td><td rowspan="2">9,048.06</td><td rowspan="2">N/A</td><td rowspan="2">85</td><td rowspan="2">-29</td><td>Nozzle</td><td>Note 8</td><td>No</td></tr>
<tr><td>Pad</td><td>Note 9</td><td>No</td></tr>
</table>

Chamber design MDMT is -29 °C
Chamber rated MDMT is -29 °C @ 7,926.8 kPa

Chamber MAWP hot & corroded is 7,926.8 kPa @ 85 °C

Chamber MAP cold & new is 7,961.61 kPa @ 25 °C

This pressure chamber is not designed for external pressure.

Pressure Summary for Shell side chamber

Identifier	P Design (kPa)	T Design (°C)	MAWP (kPa)	MAP (kPa)	MAEP (kPa)	T_e external (°C)	MDMT (°C)	MDMT Exemption		Impact Tested
Tubesheet	7,700.01	85	17,365.01	18,255.68	8,970.11	85	-49	Note 4		No
Shell #1	7,700.01	85	8,290.55	9,452.05	N/A	85	-29	Note 3		No
Rear Tubesheet	7,700.01	85	17,365.01	18,255.68	8,970.11	85	-49	Note 4		No
Tubes	7,700.01	85	18,298.14	18,298.14	26,176.67	85	N/A	N/A		No
Shell Side Flange (front)	7,700.01	85	7,961.61	7,961.61	N/A	85	-29	Note 10		No
Shell Side Flange (front) - Flange Hub	7,700.01	85	8,290.65	9,452.05	N/A	85	-29	Note 3		No
Shell Side Flange (rear)	7,700.01	85	7,961.61	7,961.61	N/A	85	-29	Note 10		No
Shell Side Flange (rear) - Flange Hub	7,700.01	85	8,290.65	9,452.05	N/A	85	-29	Note 3		No
Saddle	7,700.01	85	7,961.61	N/A	N/A	N/A	N/A	N/A		N/A
6" Two Nozzles (N3 A/B)	7,700.01	85	7,999.13	9,025.34	N/A	85	-29	Nozzle	Note 11	No
								Pad	Note 12	No
6" Two Nozzles (N4 A/B)	7,700.01	85	7,998.49	9,024.71	N/A	85	-29	Nozzle	Note 11	No
								Pad	Note 12	No

Chamber design MDMT is -29 °C
Chamber rated MDMT is -29 °C @ 7,961.61 kPa

Chamber MAWP hot & corroded is 7,961.61 kPa @ 85 °C

Chamber MAP cold & new is 7,961.61 kPa @ 25 °C

This pressure chamber is not designed for external pressure.

Notes for MDMT Rating:

Note #	Exemption	Details
1.	Straight Flange governs MDMT	
2.	Material is impact test exempt per UG-20(f)	UCS-66 governing thickness = 24 mm
3.	Material is impact test exempt per UG-20(f)	UCS-66 governing thickness = 25 mm
4.	Tubesheet is impact tested to -46 °C with an additional 3 °C reduction per UCS-66(g)	UCS-66 governing thickness = 32.5 mm
5.	Straight Flange governs MDMT	
6.	Material is impact test exempt per UCS-66(d) (NPS 4 or smaller pipe)	
7.	UCS-66(b)(1)(b) has been applied. Flange is impact test exempt per UG-20(f) UCS-66 governing thickness = 25 mm	Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C
8.	Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -24.98 °C Fig UCS-66.1M MDMT reduction = 7.8 °C, (coincident ratio = 0.8614)	UCS-66 governing thickness = 11.11 mm.
9.	Pad is impact test exempt per UG-20(f)	UCS-66 governing thickness = 25 mm.
10.	Flange is impact test exempt per UG-20(f) UCS-66 governing thickness = 25 mm	Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C
11.	Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -28.75 °C Fig UCS-66.1M MDMT reduction = 10.6 °C, (coincident ratio = 0.8113)	UCS-66 governing thickness = 9.6 mm.
12.	Pad is impact test exempt per UG-20(f)	UCS-66 governing thickness = 20 mm.

Design notes are available on the Settings Summary page.

Revision History

No.	Date	Operator	Notes
0	10/30/2014	Muhammad.Rohail	New vessel created Heat Exchanger. [COMPRESS 2014 Build 7400]

Settings Summary

COMPRESS 2014 Build 7400

Units: SI

Datum Line Location: 0.00 mm from right seam

Design

ASME Section VIII Division 1, 2013 Edition Metric

Design or Rating:	Get Thickness from Pressure
Minimum thickness:	1.5 mm per UG-16(b)
Design for cold shut down only:	No
Design for lethal service (full radiography required):	No
Design nozzles for:	Design P, find nozzle MAWP and MAP
Corrosion weight loss:	100% of theoretical loss
UG-23 Stress Increase:	1.20
Skirt/legs stress increase:	1.0
Minimum nozzle projection:	152.4 mm
Juncture calculations for $\alpha > 30$ only:	Yes
Preheat P-No 1 Materials > 1.25" and <= 1.50" thick:	No
UG-37(a) shell tr calculation considers longitudinal stress:	No

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

Hydro/Pneumatic Test

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

Required Marking - UG-116

Tube Side	
UG-116(e) Radiography:	RT1
UG-116(f) Postweld heat treatment:	None
Shell Side	
UG-116(e) Radiography:	RT1
UG-116(f) Postweld heat treatment:	None

Code Cases\Interpretations

Use Code Case 2547:	No
Use Code Case 2695:	No
Apply interpretation VIII-1-83-66:	Yes
Apply interpretation VIII-1-86-175:	Yes
Apply interpretation VIII-1-01-37:	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:	Yes

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

Radiography Summary

Radiography for 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	Full UW-11(a) / Type 1	RT1
Front Channel	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	C	Full UW-11(a) / Type 1	RT1
Tube Side Flange (front)	N/A	Seamless No RT	C	Full UW-11(a) / Type 1	N/A	N/A / Gasketed	RT1
Tubesheet	N/A	Seamless No RT[1]	N/A	N/A / Gasketed	N/A	N/A / Gasketed	N/A
Rear Tubesheet	N/A	Seamless No RT[1]	N/A	N/A / Gasketed	N/A	N/A / Gasketed	N/A
Rear Channel	A	Full UW-11(a) / Type 1	C	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	RT1
Tube Side Flange (rear)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
Rear Channel Head	N/A	Seamless No RT	B	Full UW-11(a) / Type 1	N/A	N/A	RT1
Tubes	N/A	Seamless No RT	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**		
8" Two Nozzles (N1 A/B)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
8" Two Nozzles (N9)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Nozzle Flange	**Longitudinal Seam**		**Flange Face**		**Nozzle to Flange Circumferential Seam**		
ASME B16.5/16.47 flange attached to 8" Two Nozzles (N1 A/B)	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 8" Two Nozzles (N9)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	UW-11(a)(4) exempt / Type 1	N/A
Tube side chamber - UG-116(e) Radiography: **RT1**							

Radiography for 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 / Gasketed	N/A
Shell #1	A	Full UW-11(a) / Type 1	C	Full UW-11(a) / Type 1	C	Full UW-11(a) / Type 1	RT1
Shell Side Flange (front)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
Shell Side Flange (rear)	N/A	Seamless No RT	C	Full UW-11(a) / Type 1	N/A	N/A / Gasketed	RT1
Rear Tubesheet	N/A	Seamless No RT[1]	N/A	N/A / Gasketed	N/A	N/A / Gasketed	N/A
Nozzle	**Longitudinal Seam**		**Nozzle to Vessel Circumferential Seam**		**Nozzle free end Circumferential Seam**		
6" Two Nozzles (N3 A/B)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
6" Two Nozzles (N4 A/B)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Nozzle Flange	**Longitudinal Seam**		**Flange Face**		**Nozzle to Flange Circumferential Seam**		
ASME B16.5/16.47 flange attached to 6" Two Nozzles (N3 A/B)	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 6" Two Nozzles (N4 A/B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	UW-11(a)(4) exempt / Type 1	N/A
Shell side chamber - UG-116(e) Radiography: **RT1**							

[1]Tubesheets are always considered to be seamless.

Thickness Summary

Component Identifier	Material	Diameter (mm)	Length (mm)	Nominal t (mm)	Design t (mm)	Total Corrosion (mm)	Joint E	Load
Front Head	SA-516 70	700 ID	199	24*	22.59	3	1.00	Internal
Straight Flange on Front Head	SA-516 70	700 ID	50	24	23.38	3	1.00	Internal
Front Channel	SA-516 70	700 ID	600	25	23.38	3	1.00	Internal
Tubesheet	SA-350 LF2 Cl 1	970 OD	130	130	116.55	6	1.00	Unknown
Tubes	SA-179 Smls. Tube	19.05 OD	12,000	2.77	1.22	0	1.00	External
Shell #1	SA-516 70	700 ID	11,390.71	25	23.38	3	1.00	Internal
Rear Tubesheet	SA-350 LF2 Cl 1	970 OD	130	130	116.55	6	1.00	Unknown
Rear Channel	SA-516 70	700 ID	600	25	23.38	3	1.00	Internal
Straight Flange on Rear Channel Head	SA-516 70	700 ID	50	24	23.38	3	1.00	Internal
Rear Channel Head	SA-516 70	700 ID	199	24*	22.59	3	1.00	Internal

Nominal t: Vessel wall nominal thickness

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

Joint E: Longitudinal seam joint efficiency

* Head minimum thickness after forming

Load

internal: Circumferential stress due to internal pressure governs

external: External pressure governs

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

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

Weight Summary

Component	Weight (kg) Contributed by Vessel Elements										Surface Area m2
	Metal New*	Metal Corroded*	Insulation	Insulation Supports	Lining	Piping + Liquid	Operating Liquid		Test Liquid		
							New	Corroded	New	Corroded	
Front Head	136.8	120.8	0	0	0	0	0	0	64.1	66	0.8
Front Channel	260.2	230	0	0	0	0	0	0	304.5	309.9	1.38
Tubesheet	653.2	567.3	0	0	0	0	0	0	0	0	0.4
Shell #1	5,071.8	4,481.7	0	0	0	0	0	0	2,725.4	2,803.5	26.79
Tubes	7,151	7,151	0	0	0	0	0	0	923	923	N/A
Rear Tubesheet	653.2	567.3	0	0	0	0	0	0	0	0	0.4
Rear Channel	260.2	230	0	0	0	0	0	0	304.5	309.9	1.38
Rear Channel Head	136.8	120.8	0	0	0	0	0	0	64.1	66	0.8
Saddle	175.1	175.1	0	0	0	0	0	0	0	0	2.45
TOTAL:	**14,498.4**	**13,643.9**	**0**	**0**	**0**	**0**	**0**	**0**	**4,385.5**	**4,478.2**	**34.38**

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

Component	Weight (kg) Contributed by Attachments									Surface Area m2
	Body Flanges		Nozzles & Flanges		Packed Beds	Trays Baffles Pass Partitions	Tray Supports	Rings & Clips	Vertical Loads	
	New	Corroded	New	Corroded						
Front Head	0	0	0	0	0	0	0	0	0	0
Front Channel	365.5	356.3	104.4	98.9	0	0	0	0	0	0.91
Tubesheet	0	0	0	0	0	0	0	0	0	0
Shell #1	729.2	711	138.9	130.4	0	628.9[1]	0	0	0	1.61
Rear Tubesheet	0	0	0	0	0	0	0	0	0	0
Rear Channel	365.5	356.3	79.4	76.7	0	0	0	0	0	0.91
Rear Channel Head	0	0	0	0	0	0	0	0	0	0
TOTAL:	**1,460.1**	**1,423.6**	**322.7**	**306**	**0**	**628.9**	**0**	**0**	**0**	**3.43**

Vessel operating weight, Corroded:	16,002 kg
Vessel operating weight, New:	16,910 kg
Vessel empty weight, Corroded:	16,002 kg
Vessel empty weight, New:	16,910 kg
Vessel test weight, New:	21,296 kg
Vessel test weight, Corroded:	20,481 kg
Vessel surface area:	37.82 m^2

Vessel center of gravity location - from datum - lift condition

Vessel Lift Weight, New:	16,910 kg
Center of Gravity:	6,794.72 mm

Vessel Capacity

Shell side Capacity** (New):	2,723 liters
Shell side Capacity** (Corroded):	2,801 liters
Tube side Capacity** (New):	1,654 liters
Tube side Capacity** (Corroded):	1,668 liters

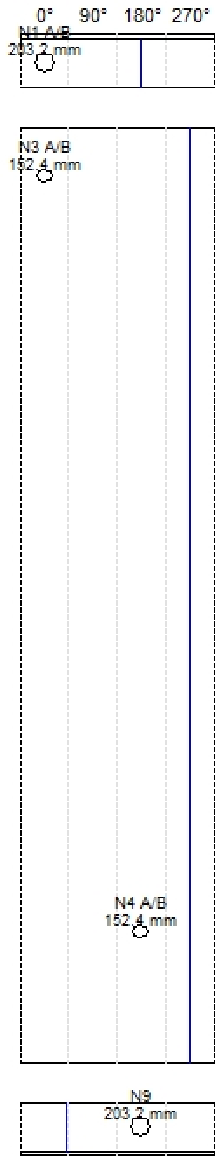
**The shell and tube capacity does not include volume of nozzle, piping or other attachments.
[1]Baffle weights are approximated.

Long Seam Summary

Shell Long Seam Angles	
Component	**Seam 1**
Front Channel	180°
Shell #1	270°
Rear Channel	40°

Shell Plate Lengths		
Component	**Starting Angle**	**Plate 1**
Front Channel	180°	2,277.65 mm
Shell #1	270°	2,277.65 mm
Rear Channel	40°	2,277.65 mm

*Plate Lengths use the circumference of the vessel based on the mid diameter of the components



Shell Rollout

Hydrostatic Test

Shop test pressure determination for Tube side chamber based on MAWP per UG-99(b)

Shop hydrostatic test gauge pressure is 10,304.84 kPa at 25 °C (the chamber MAWP = 7,926.8 kPa)

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

Identifier	Local test pressure kPa	Test liquid static head kPa	UG-99(b) stress ratio	UG-99(b) pressure factor	Stress during test MPa	Allowable test stress MPa	Stress excessive?
Front Head (1)	10,314.63	9.8	1	1.30	135.38	235.8	No
Straight Flange on Front Head	10,314.63	9.8	1	1.30	155.522	235.8	No
Front Channel	10,314.63	9.8	1	1.30	149.503	235.8	No
Rear Channel	10,314.63	9.8	1	1.30	149.503	235.8	No
Straight Flange on Rear Channel Head	10,314.63	9.8	1	1.30	155.522	235.8	No
Rear Channel Head	10,314.63	9.8	1	1.30	135.38	235.8	No
Tubes	10,314.58	9.75	1	1.30	33.641	162	No
Tube Side Flange (front) - Flange Hub	10,314.63	9.8	1	1.30	149.503	223.2	No
Tube Side Flange (rear) - Flange Hub	10,314.63	9.8	1	1.30	149.503	223.2	No
Tube Side Flange (front)	10,314.63	9.8	1	1.30	308.271	334.8	No
Tubesheet	10,314.63	9.8	1	1.30	See tubesheet report		
Rear Tubesheet	10,314.63	9.8	1	1.30	See tubesheet report		
Tube Side Flange (rear)	10,314.63	9.8	1	1.30	308.271	334.8	No
8" Two Nozzles (N1 A/B)	10,307.53	2.69	1	1.30	223.872	351	No
8" Two Nozzles (N9)	10,317.57	12.74	1	1.30	224.09	351	No

Notes:
(1) Front Head limits the UG-99(b) stress ratio.
(2) P_L stresses at nozzle openings have been estimated using the method described in Division 2 Part 4.5.
(3) 1.5*0.9*S_y used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.
(4) 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.

The test temperature of 25 °C is warmer than the minimum recommended temperature of -12 °C so the brittle fracture provision of UG-99(h) has been met.

Shop test pressure determination for Shell side chamber based on MAWP per UG-99(b)

Shop hydrostatic test gauge pressure is 10,350.09 kPa at 25 °C (the chamber MAWP = 7,961.61 kPa)

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

Identifier	Local test pressure kPa	Test liquid static head kPa	UG-99(b) stress ratio	UG-99(b) pressure factor	Stress during test MPa	Allowable test stress MPa	Stress excessive?
Shell #1 (1)	10,359.65	9.55	1	1.30	150.155	235.8	No
Tubes	10,359.6	9.5	N/A	1.30	NI	NI	NI
Shell Side Flange (front) - Flange Hub	10,359.65	9.55	1	1.30	150.155	223.2	No
Shell Side Flange (rear) - Flange Hub	10,359.65	9.55	1	1.30	150.155	223.2	No
Tubesheet	10,359.65	9.55	1	1.30	See tubesheet report		
Shell Side Flange (front)	10,359.65	9.55	1	1.30	309.617	334.8	No
Shell Side Flange (rear)	10,359.65	9.55	1	1.30	309.617	334.8	No
Rear Tubesheet	10,359.65	9.55	1	1.30	See tubesheet report		
6" Two Nozzles (N3 A/B)	10,352.54	2.45	1	1.30	197.455	351	No
6" Two Nozzles (N4 A/B)	10,362.34	12.25	1	1.30	197.657	351	No

Notes:
(1) Shell #1 limits the UG-99(b) stress ratio.
(2) NI indicates that test stress was not investigated.
(3) P_L stresses at nozzle openings have been estimated using the method described in Division 2 Part 4.5.
(4) 1.5*0.9*S_y used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.
(5) 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.

The test temperature of 25 °C is warmer than the minimum recommended temperature of -12 °C so the brittle fracture provision of UG-99(h) has been met.

Vacuum Summary

Component	Line of Support	Elevation above Datum (mm)	Length Le (mm)
Front Head	-	13,802.29	N/A
-	1/3 depth of Front Head	13,662.62	N/A
Straight Flange on Front Head Left	-	13,603.29	888.56
Straight Flange on Front Head Right	-	13,553.29	888.56
Front Channel Left	-	13,553.29	888.56
Front Channel Right	-	12,953.29	888.56
Tubesheet	-	12,781.45	N/A
-	Tube Side Flange (front)	12,774.07	N/A
-	Shell Side Flange (front)	12,649.22	N/A
Shell #1 Left	-	12,472	11,745.16
Shell #1 Right	-	1,081.29	11,745.16
-	Shell Side Flange (rear)	904.07	N/A
Rear Tubesheet	-	781.45	N/A
-	Tube Side Flange (rear)	779.22	N/A
Rear Channel Left	-	600	888.56
Rear Channel Right	-	0	888.56
Straight Flange on Rear Channel Head Left	-	0	888.56
Straight Flange on Rear Channel Head Right	-	-50	888.56
-	1/3 depth of Rear Channel Head	-109.33	N/A
Rear Channel Head	-	-249	N/A

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

Front Channel

ASME Section VIII Division 1, 2013 Edition Metric

Component: Cylinder
Material specification: SA-516 70 (II-D Metric p. 22, ln. 6)
Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.8 kPa (SG = 1, H_s = 1,000 mm, Horizontal test head)

Corrosion allowance Inner C = 3 mm Outer C = 0 mm

Design MDMT = -29 °C
Rated MDMT = -29 °C

No impact test performed
Material is not normalized
Material is not produced to Fine Grain Practice
PWHT is not performed

Radiography:	Longitudinal joint -	Full UW-11(a) Type 1
	Left circumferential joint -	Full UW-11(a) Type 1
	Right circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 260.2 kg	corr = 230 kg
Capacity	New = 230.91 liters	corr = 234.88 liters

ID = 700 mm
Length L_c = 600 mm
t = 25 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*22 / (353 + 0.60*22) - 0
= 8,290.65 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*25 / (350 + 0.60*25)
= 9,452.05 kPa

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*25 / 362.5)*(1 - 362.5 / ∞)

= 3.4483%

The extreme fiber elongation does not exceed 5%.

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 22)
= 0.007333
B = 119.47 MPa
S = 138 / 1.00 = 138 MPa
S_{cHC} = min(B, S) = 119.47 MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 25)
= 0.008333
B = 119.63 MPa
S = 138 / 1.00 = 138 MPa
S_{cHN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 25)
= 0.008333
B = 119.63 MPa
S = 138 / 1.00 = 138 MPa
S_{cCN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 22)
= 0.007333
B = 119.47 MPa
S = 138 / 1.00 = 138 MPa
S_{cCC} = min(B, S) = 119.47 MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 22)
= 0.007333
B = 119.47 MPa
S = 138 / 1.00 = 138 MPa
S_{cVC} = min(B, S) = 119.47 MPa

Shell #1

ASME Section VIII Division 1, 2013 Edition Metric

Component:	Cylinder
Material specification:	SA-516 70 (II-D Metric p. 22, ln. 6)

Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.55 kPa (SG = 1, H_s = 975 mm, Horizontal test head)

Corrosion allowance	Inner C = 3 mm	Outer C = 0 mm

Design MDMT = -29 °C	No impact test performed
Rated MDMT = -29 °C	Material is not normalized
	Material is not produced to Fine Grain Practice
	PWHT is not performed

Radiography:		
	Longitudinal joint -	Full UW-11(a) Type 1
	Left circumferential joint -	Full UW-11(a) Type 1
	Right circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 5,071.8 kg	corr = 4,481.7 kg
Capacity	New = 2,640.23 liters	corr = 2,715.7 liters

ID	=	700 mm
Length L_c	=	11,390.71 mm
t	=	25 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*22 / (353 + 0.60*22) - 0
= 8,290.55 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*25 / (350 + 0.60*25)
= 9,452.05 kPa

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*25 / 362.5)*(1 - 362.5 / ∞)

= 3.4483%

The extreme fiber elongation does not exceed 5%.

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= $0.125 / (375 / 22)$
= 0.007333
B = 119.47 MPa
S = 138 / 1.00 = 138 MPa
S_{cHC} = min(B, S) = 119.47 MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= $0.125 / (375 / 25)$
= 0.008333
B = 119.63 MPa
S = 138 / 1.00 = 138 MPa
S_{cHN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= $0.125 / (375 / 25)$
= 0.008333
B = 119.63 MPa
S = 138 / 1.00 = 138 MPa
S_{cCN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= $0.125 / (375 / 22)$
= 0.007333
B = 119.47 MPa
S = 138 / 1.00 = 138 MPa
S_{cCC} = min(B, S) = 119.47 MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= $0.125 / (375 / 22)$
= 0.007333
B = 119.47 MPa
S = 138 / 1.00 = 138 MPa
S_{cVC} = min(B, S) = 119.47 MPa

Rear Channel

ASME Section VIII Division 1, 2013 Edition Metric

Component: Cylinder
Material specification: SA-516 70 (II-D Metric p. 22, ln. 6)
Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.8 kPa (SG = 1, H_s = 1,000 mm, Horizontal test head)

Corrosion allowance   Inner C = 3 mm   Outer C = 0 mm

Design MDMT = -29 °C   No impact test performed
Rated MDMT = -29 °C   Material is not normalized
Material is not produced to Fine Grain Practice
PWHT is not performed

Radiography:	Longitudinal joint -	Full UW-11(a) Type 1
	Left circumferential joint -	Full UW-11(a) Type 1
	Right circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 260.2 kg	corr = 230 kg
Capacity	New = 230.91 liters	corr = 234.88 liters

ID = 700 mm
Length L_c = 600 mm
t = 25 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*22 / (353 + 0.60*22) - 0
= 8,290.65 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*25 / (350 + 0.60*25)
= 9,452.05 kPa

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= (50*25 / 362.5)*(1 - 362.5 / ∞)

= 3.4483%

The extreme fiber elongation does not exceed 5%.

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cHC}	=	min(B, S) = 119.47 MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 25)
	=	0.008333
B	=	119.63 MPa
S	=	138 / 1.00 = 138 MPa
S_{cHN}	=	min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 25)
	=	0.008333
B	=	119.63 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCN}	=	min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCC}	=	min(B, S) = 119.47 MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cVC}	=	min(B, S) = 119.47 MPa

Front Head

ASME Section VIII Division 1, 2013 Edition Metric

Component:	Ellipsoidal Head
Material Specification:	SA-516 70 (II-D Metric p.22, ln. 6)

Straight Flange governs MDMT

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_s= 0 kPa (SG=1, H_s=0 mm Operating head)
P_{th}= 9.8 kPa (SG=1, H_s=1000 mm Horizontal test head)

Corrosion allowance: Inner C = 3 mm Outer C = 0 mm

Design MDMT = -29°C	No impact test performed
Rated MDMT = -29°C	Material is not normalized
	Material is not produced to fine grain practice
	PWHT is not performed
	Do not Optimize MDMT / Find MAWP

Radiography:	Category A joints -	Seamless No RT
	Head to shell seam -	Full UW-11(a) Type 1

Estimated weight*:	new = 136.8 kg	corr = 120.8 kg
Capacity*:	new = 64.1 liters	corr = 66 liters

* includes straight flange

Inner diameter	=	700 mm
Minimum head thickness	=	24 mm
Head ratio D/2h	=	2 (new)
Head ratio D/2h	=	1.9831 (corroded)
Straight flange length L_{sf}	=	50 mm
Nominal straight flange thickness t_{sf}	=	24 mm

Results Summary

The governing condition is internal pressure.

Minimum thickness per UG-16	=	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	=	22.59 mm
Maximum allowable working pressure (MAWP)	=	8,252.97 kPa
Maximum allowable pressure (MAP)	=	9,398.41 kPa

K (Corroded)

$K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (706 / (2*178))^2]=0.988812$

K (New)

$K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (700 / (2*175))^2]=1$

Design thickness for internal pressure, (Corroded at 85 °C) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 7,700.01*706*0.988812 / (2*138,000*1 - 0.2*7,700.01) + 3
= 22.59 mm

The head internal pressure design thickness is 22.59 mm.

Maximum allowable working pressure, (Corroded at 85 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*138,000*1*21 / (0.988812*706 +0.2*21) - 0
= 8,252.97 kPa

The maximum allowable working pressure (MAWP) is 8,252.97 kPa.

Maximum allowable pressure, (New at 25 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*138,000*1*24 / (1*700 +0.2*24) - 0
= 9,398.41 kPa

The maximum allowable pressure (MAP) is 9,398.41 kPa.

% Extreme fiber elongation - UCS-79(d)

EFE = $(75*t / R_f)*(1 - R_f / R_o)$
= (75*24 / 131)*(1 - 131 / ∞)
= 13.7405%

The extreme fiber elongation exceeds 5 percent and the thickness exceeds 16 mm;. Heat treatment per UCS-56 is required if fabricated by cold forming.

Straight Flange on Front Head

ASME Section VIII Division 1, 2013 Edition Metric

Component: Straight Flange
Material specification: SA-516 70 (II-D Metric p. 22, ln. 6)
Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 24 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.8 kPa (SG = 1, H_s = 1,000 mm, Horizontal test head)

Corrosion allowance Inner C = 3 mm Outer C = 0 mm

Design MDMT = -29 °C
Rated MDMT = -29 °C

No impact test performed
Material is not normalized
Material is not produced to Fine Grain Practice
PWHT is not performed

Radiography: Longitudinal joint - Seamless No RT
Circumferential joint - Full UW-11(a) Type 1

Estimated weight	New = 21.4 kg	corr = 18.8 kg
Capacity	New = 19.24 liters	corr = 19.57 liters

ID = 700 mm
Length L_c = 50 mm
t = 24 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*21 / (353 + 0.60*21) - 0
= 7,926.8 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*24 / (350 + 0.60*24)
= 9,088.91 kPa

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*24 / 362)*(1 - 362 / \infty)$

$= 3.3149\%$

The extreme fiber elongation does not exceed 5%.

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

$A = 0.125 / (R_o / t)$
$= 0.125 / (374 / 21)$
$= 0.007019$
$B = 119.42$ MPa
$S = 138 / 1.00 = 138$ MPa
$S_{cHC} = \min(B, S) = 119.42$ MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

$A = 0.125 / (R_o / t)$
$= 0.125 / (374 / 24)$
$= 0.008021$
$B = 119.58$ MPa
$S = 138 / 1.00 = 138$ MPa
$S_{cHN} = \min(B, S) = 119.58$ MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

$A = 0.125 / (R_o / t)$
$= 0.125 / (374 / 24)$
$= 0.008021$
$B = 119.58$ MPa
$S = 138 / 1.00 = 138$ MPa
$S_{cCN} = \min(B, S) = 119.58$ MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

$A = 0.125 / (R_o / t)$
$= 0.125 / (374 / 21)$
$= 0.007019$
$B = 119.42$ MPa
$S = 138 / 1.00 = 138$ MPa
$S_{cCC} = \min(B, S) = 119.42$ MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

$A = 0.125 / (R_o / t)$
$= 0.125 / (374 / 21)$
$= 0.007019$
$B = 119.42$ MPa
$S = 138 / 1.00 = 138$ MPa
$S_{cVC} = \min(B, S) = 119.42$ MPa

Straight Flange on Rear Channel Head

ASME Section VIII Division 1, 2013 Edition Metric

Component: Straight Flange
Material specification: SA-516 70 (II-D Metric p. 22, ln. 6)
Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 24 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.8 kPa (SG = 1, H_s = 1,000 mm, Horizontal test head)

Corrosion allowance   Inner C = 3 mm   Outer C = 0 mm

Design MDMT = -29 °C   No impact test performed
Rated MDMT = -29 °C   Material is not normalized
Material is not produced to Fine Grain Practice
PWHT is not performed

Radiography: Longitudinal joint - Seamless No RT
Circumferential joint - Full UW-11(a) Type 1

Estimated weight	New = 21.4 kg	corr = 18.8 kg
Capacity	New = 19.24 liters	corr = 19.57 liters

ID = 700 mm
Length L_c = 50 mm
t = 24 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*21 / (353 + 0.60*21) - 0
= 7,926.8 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*24 / (350 + 0.60*24)
= 9,088.91 kPa

% Extreme fiber elongation - UCS-79(d)

EFE = $(50 \cdot t / R_f) \cdot (1 - R_f / R_o)$
= (50*24 / 362)*(1 - 362 / ∞)

= 3.3149%

The extreme fiber elongation does not exceed 5%.

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= 0.125 / (374 / 21)
= 0.007019
B = 119.42 MPa
S = 138 / 1.00 = 138 MPa
S_{cHC} = min(B, S) = 119.42 MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= 0.125 / (374 / 24)
= 0.008021
B = 119.58 MPa
S = 138 / 1.00 = 138 MPa
S_{cHN} = min(B, S) = 119.58 MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= 0.125 / (374 / 24)
= 0.008021
B = 119.58 MPa
S = 138 / 1.00 = 138 MPa
S_{cCN} = min(B, S) = 119.58 MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= 0.125 / (374 / 21)
= 0.007019
B = 119.42 MPa
S = 138 / 1.00 = 138 MPa
S_{cCC} = min(B, S) = 119.42 MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

A = $0.125 / (R_o / t)$
= 0.125 / (374 / 21)
= 0.007019
B = 119.42 MPa
S = 138 / 1.00 = 138 MPa
S_{cVC} = min(B, S) = 119.42 MPa

Rear Channel Head

ASME Section VIII Division 1, 2013 Edition Metric

Component: Ellipsoidal Head
Material Specification: SA-516 70 (II-D Metric p.22, ln. 6)
Straight Flange governs MDMT

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_s= 0 kPa (SG=1, H_s=0 mm Operating head)
P_{th}= 9.8 kPa (SG=1, H_s=1000 mm Horizontal test head)

Corrosion allowance: Inner C = 3 mm Outer C = 0 mm

Design MDMT = -29°C	No impact test performed
Rated MDMT = -29°C	Material is not normalized
	Material is not produced to fine grain practice
	PWHT is not performed
	Do not Optimize MDMT / Find MAWP

Radiography:	Category A joints -	Seamless No RT
	Head to shell seam -	Full UW-11(a) Type 1

Estimated weight*:	new = 136.8 kg	corr = 120.8 kg
Capacity*:	new = 64.1 liters	corr = 66 liters

* includes straight flange

Inner diameter	=	700 mm
Minimum head thickness	=	24 mm
Head ratio D/2h	=	2 (new)
Head ratio D/2h	=	1.9831 (corroded)
Straight flange length L_{sf}	=	50 mm
Nominal straight flange thickness t_{sf}	=	24 mm

Results Summary

The governing condition is internal pressure.

Minimum thickness per UG-16	=	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	=	22.59 mm
Maximum allowable working pressure (MAWP)	=	8,252.97 kPa
Maximum allowable pressure (MAP)	=	9,398.41 kPa

K (Corroded)

$K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (706 / (2*178))^2]=0.988812$

K (New)

$K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (700 / (2*175))^2]=1$

Design thickness for internal pressure, (Corroded at 85 °C) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 7,700.01*706*0.988812 / (2*138,000*1 - 0.2*7,700.01) + 3
= 22.59 mm

The head internal pressure design thickness is 22.59 mm.

Maximum allowable working pressure, (Corroded at 85 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*138,000*1*21 / (0.988812*706 +0.2*21) - 0
= 8,252.97 kPa

The maximum allowable working pressure (MAWP) is 8,252.97 kPa.

Maximum allowable pressure, (New at 25 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*138,000*1*24 / (1*700 +0.2*24) - 0
= 9,398.41 kPa

The maximum allowable pressure (MAP) is 9,398.41 kPa.

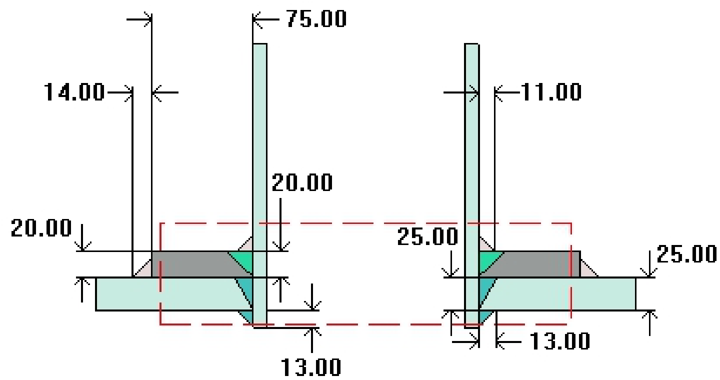
% Extreme fiber elongation - UCS-79(d)

EFE = (75*t / R_f)*(1 - R_f / R_o)
= (75*24 / 131)*(1 - 131 / ∞)
= 13.7405%

The extreme fiber elongation exceeds 5 percent and the thickness exceeds 16 mm;. Heat treatment per UCS-56 is required if fabricated by cold forming.

6" Two Nozzles (N3 A/B)

ASME Section VIII Division 1, 2013 Edition Metric



$t_{w(lower)}$ =	25 mm
Leg_{41} =	11 mm
$t_{w(upper)}$ =	20 mm
Leg_{42} =	14 mm
Leg_{43} =	13 mm
h_{new} =	13 mm
D_p =	318.28 mm
t_e =	20 mm

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

Location and Orientation

Located on:	Shell #1
Orientation:	0°
Nozzle center line offset to datum line:	11,872 mm
End of nozzle to shell center:	625 mm
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 14, ln. 19)
Description:	NPS 6 Sch 80 (XS) DN 150
Inside diameter, new:	146.33 mm
Nominal wall thickness:	10.97 mm
Corrosion allowance:	3 mm
Projection available outside vessel, Lpr:	126.3 mm
Internal projection, h_{new}:	13 mm
Projection available outside vessel to flange face, Lf:	250 mm
Local vessel minimum thickness:	25 mm
Liquid static head included:	0 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 22, ln. 6)
Diameter:	318.28 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 6 Class 600 WN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 352, ln. 31)

Blind included:	No
Rated MDMT:	-41.28°C per UCS-66(b)(1)(b)
Liquid static head:	0 kPa
MAWP rating:	9,530.01 kPa @ 85°C
MAP rating:	10,210.01 kPa @ 25°C
Hydrotest rating:	15,400.02 kPa @ 25°C
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2) For P = 7,999.13 kPa @ 85 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
32.7819	32.782	1.2019	1.769	0.8504	27.2768	1.6839	9.22	9.6

UG-41 Weld Failure Path Analysis Summary (N) 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
437,311	415,113	639,113	100,782	1,435,004	477,202	1,200,316

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	5.58	7.7	weld size is adequate
Pad to shell fillet (Leg_{42})	9.5	9.8	weld size is adequate
Nozzle to pad groove (Upper)	5.58	20	weld size is adequate

WRC 107												
Load Case	P (kPa)	P_r (N)	M_c (N-m)	V_c (N)	M_L (N-m)	V_L (N)	M_t (N-m)	Max Comb Stress (MPa)	Allow Comb Stress (MPa)	Max Local Primary Stress (MPa)	Allow Local Primary Stress (MPa)	Over stressed
Load case 1	7,999.13	5,589	3,350	4,609	3,350	4,609	4,070	188.496	414	182.635	207	No
Load case 1 (Hot Shut Down)	0	5,589	3,350	4,609	3,350	4,609	4,070	-29.227	414	-6.391	207	No
Load case 1 (Pr Reversed)	7,999.13	-5,589	3,350	4,609	3,350	4,609	4,070	**193.129**	**414**	**183.738**	**207**	No
Load case 1 (Pr Reversed) (Hot Shut Down)	0	-5,589	3,350	4,609	3,350	4,609	4,070	29.413	414	6.391	207	No

Calculations for internal pressure 7,999.13 kPa @ 85 °C

Fig UCS-66.2 general note (1) applies.

Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -28.75 °C
Fig UCS-66.1M MDMT reduction = 10.6 °C, (coincident ratio = 0.8113).

Pad is impact test exempt per UG-20(f).

Nozzle UCS-66 governing thk:	9.6 mm
Nozzle rated MDMT:	-39.35 °C
Pad UCS-66 governing thickness:	20 mm
Pad rated MDMT:	-29 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(152.33, 76.16 + (10.97 - 3) + (25 - 3))
= 152.33 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(25 - 3), 2.5*(10.97 - 3) + 20)
= 39.93 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(10, 2.5*(25 - 3), 2.5*(10.97 - 3 - 3))
= 10 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 7,999.1323*76.16 / (118,000*1 - 0.6*7,999.1323)
= 5.38 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 7,999.1323*353 / (138,000*1 - 0.6*7,999.1323)
= 21.2 mm

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

t_r = P*R / (S*E - 0.6*P)
= 7,999.1323*353 / (138,000*1 - 0.6*7,999.1323)
= 21.2 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

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

= $(152.33*21.2*1 + 2*7.97*21.2*1*(1 - 0.8551)) / 100$
= 32.7819 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.2019 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(152.33*(1*22 - 1*21.2) - 2*7.97*(1*22 - 1*21.2)*(1 - 0.8551)) / 100$
= 1.2019 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(2*(22 + 7.97)*(1*22 - 1*21.2) - 2*7.97*(1*22 - 1*21.2)*(1 - 0.8551)) / 100$
= 0.4619 cm^2

A_2 = smaller of the following= 1.769 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $(5*(7.97 - 5.38)*0.8551*22) / 100$
= 2.4368 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $(2*(7.97 - 5.38)*(2.5*7.97 + 20)*0.8551) / 100$
= 1.769 cm^2

A_3 = smaller of the following= 0.8504 cm^2

= $5*t*t_i*f_{r2}$
= $(5*22*4.97*0.8551) / 100$
= 4.6775 cm^2

= $5*t_i*t_i*f_{r2}$
= $(5*4.97*4.97*0.8551) / 100$
= 1.0573 cm^2

= $2*h*t_i*f_{r2}$
= $(2*10*4.97*0.8551) / 100$
= 0.8504 cm^2

A_{41} = Leg^2*f_{r3}
= $(11^2*0.8551) / 100$
= 1.0348 cm^2

A_{42} = Leg^2*f_{r4}
= $(0^2*1) / 100$
= 0 cm^2

(Part of the weld is outside of the limits)

A_{43} = Leg^2*f_{r2}
= $(8.71^2*0.8551) / 100$
= 0.649 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((304.66 - 152.33 - 2*7.97)*20*1) / 100
= 27.2768 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 1.2019 + 1.769 + 0.8504 + 1.0348 + 0 + 0.649 + 27.2768
= 32.782 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 7.97 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 5.58 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 19 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 9.5 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*14 = 9.8 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 7,999.1323*76.16 / (118,000*1 - 0.6*7,999.1323) + 3
= 8.38 mm

$t_{a\ UG-22}$ = 7.35 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[8.38 , 7.35]
= 8.38 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 7,999.1323*353 / (138,000*1 - 0.6*7,999.1323) + 3
= 24.2 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[24.2 , 4.5]
= 24.2 mm

t_b = min[t_{b3} , t_{b1}]

$= \min[\ 9.22\ ,\ 24.2\ ]$
$= 9.22$ mm

$t_{UG-45} = \max[\ t_a\ ,\ t_b\ ]$
$= \max[\ 8.38\ ,\ 9.22\ ]$
$= 9.22$ mm

Available nozzle wall thickness new, t_n = 0.875*10.97 = 9.6 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa
Lower fillet weld in shear:	0.49*118 =	57.82 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*168.28*11*57.82 = 168,116.49 N

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*318.28*14*67.62 = 473,288.18 N

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*160.3*7.97*82.6 = 165,825.13 N

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*168.28*22*102.12 = 593,844.88 N

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*168.28*8.71*57.82 = 133,183.19 N

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*168.28*20*102.12 = 539,858.98 N

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2 * t_n * f_{r1} * (E_1 * t - F * t_r)) * S_v$
$= (3{,}278.1869 - 120.1933 + 2*7.97*0.8551*(1*22 - 1*21.2))*138$
$=$ 437,310.66 N

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42}) * S_v$
$= (176.9029 + 2{,}727.676 + 103.4837 + 0)*138$
$=$ 415,112.68 N

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2 * t_n * t * f_{r1}) * S_v$

= $(176.9029 + 85.0448 + 103.4837 + 64.9031 + 2*7.97*22*0.8551)*138$

= 100,782.28 N

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$

= $(176.9029 + 85.0448 + 2{,}727.676 + 103.4837 + 0 + 64.9031 + 2*7.97*22*0.8551)*138$

= 477,201.61 N

Load for path 1-1 lesser of W or W_{1-1} = 415,112.68 N
Path 1-1 through (2) & (3) = 473,288.18 + 165,825.13 = 639,113.31 N
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} = 100,782.28 N
Path 2-2 through (1), (4), (5), (6) = 168,116.49 + 593,844.88 + 133,183.19 + 539,858.98 = 1,435,003.54 N
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} = 437,310.66 N
Path 3-3 through (2), (4), (5) = 473,288.18 + 593,844.88 + 133,183.19 = 1,200,316.25 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1 (Pr Reversed)

Applied Loads

Radial load:	P_r =	-5,589	N
Circumferential moment:	M_c =	3,350	N-m
Circumferential shear:	V_c =	4,609	N
Longitudinal moment:	M_L =	3,350	N-m
Longitudinal shear:	V_L =	4,609	N
Torsion moment:	M_t =	4,070	N-m
Internal pressure:	P =	7,999.13	kPa
Mean shell radius:	R_m =	364	mm
Local shell thickness:	T =	22	mm
Shell yield stress:	S_y =	242	MPa
Design factor:		3	

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 364 / 22 = 16.5455$

$\beta = 0.875*r_o / R_m = 0.875*159.14 / 364 = 0.3825$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =128.353 MPa

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =64.176 MPa

Maximum combined stress (P_L+P_b+Q) = 157.56 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 134.37 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	N_ϕ / (P / R_m)	1.2801	0	0	0	0	0.896	0.896	0.896	0.896
4C*	N_ϕ / (P / R_m)	2.0646	1.441	1.441	1.441	1.441	0	0	0	0
1C	M_ϕ / P	0.0559	0	0	0	0	3.875	-3.875	3.875	-3.875
2C-1	M_ϕ / P	0.0238	1.648	-1.648	1.648	-1.648	0	0	0	0
3A*	N_ϕ / [M_c / (R_m2*β)]	0.7066	0	0	0	0	-2.124	-2.124	2.124	2.124
1A	M_ϕ / [M_c / (R_m*β)]	0.0747	0	0	0	0	-22.277	22.277	22.277	-22.277
3B*	N_ϕ / [M_L / (R_m2*β)]	1.5212	-4.571	-4.571	4.571	4.571	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0201	-5.992	5.992	5.992	-5.992	0	0	0	0
Pressure stress*			128.353	128.353	128.353	128.353	128.353	128.353	128.353	128.353
Total circumferential stress			120.879	129.566	142.004	126.726	108.723	145.528	157.525	105.221
Primary membrane circumferential stress*			125.223	125.223	134.365	134.365	127.126	127.126	131.373	131.373
3C*	N_x / (P / R_m)	1.2801	0.896	0.896	0.896	0.896	0	0	0	0
4C*	N_x / (P / R_m)	2.0646	0	0	0	0	1.441	1.441	1.441	1.441
1C-1	M_x / P	0.0462	3.199	-3.199	3.199	-3.199	0	0	0	0
2C	M_x / P	0.03	0	0	0	0	2.075	-2.075	2.075	-2.075
4A*	N_x / [M_c / (R_m2*β)]	1.6475	0	0	0	0	-4.95	-4.95	4.95	4.95
2A	M_x / [M_c / (R_m*β)]	0.0355	0	0	0	0	-10.59	10.59	10.59	-10.59
4B*	N_x / [M_L / (R_m2*β)]	0.6875	-2.068	-2.068	2.068	2.068	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0351	-10.466	10.466	10.466	-10.466	0	0	0	0
Pressure stress*			64.176	64.176	64.176	64.176	64.176	64.176	64.176	64.176
Total longitudinal stress			55.737	70.271	80.807	53.476	52.152	69.182	83.234	57.902
Primary membrane longitudinal stress*			63.004	63.004	67.141	67.141	60.667	60.667	70.568	70.568
Shear from M_t			1.165	1.165	1.165	1.165	1.165	1.165	1.165	1.165
Circ shear from V_c			0.421	0.421	-0.421	-0.421	0	0	0	0
Long shear from V_L			0	0	0	0	-0.421	-0.421	0.421	0.421
Total Shear stress			1.586	1.586	0.745	0.745	0.745	0.745	1.586	1.586
Combined stress (P_L+P_b+Q)			120.92	129.608	142.011	126.733	108.73	145.535	157.559	105.276

Note: * denotes primary stress.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 364 / 42 = 8.6667$

$\beta = 0.875*r_o / R_m = 0.875*84.14 / 364 = 0.2023$

Pressure stress intensity factor, I = 1.4055 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = I*P*R_i / T =180.394 MPa

Local longitudinal pressure stress = I*P*R_i / (2*T) =90.197 MPa

Maximum combined stress (P_L+P_b+Q) = 193.13 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 183.74 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	1.3466	0	0	0	0	0.49	0.49	0.49	0.49
4C*	N_ϕ / (P / R_m)	1.5144	0.552	0.552	0.552	0.552	0	0	0	0
1C	M_ϕ / P	0.1266	0	0	0	0	2.406	-2.406	2.406	-2.406
2C-1	M_ϕ / P	0.0927	1.765	-1.765	1.765	-1.765	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.2537	0	0	0	0	-0.758	-0.758	0.758	0.758
1A	M_ϕ / [M_c / (R_m*β)]	0.097	0	0	0	0	-15.01	15.01	15.01	-15.01
3B*	N_ϕ / [M_L / (R_m^2*β)]	0.9373	-2.792	-2.792	2.792	2.792	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0491	-7.598	7.598	7.598	-7.598	0	0	0	0
Pressure stress*			180.394	180.394	180.394	180.394	128.353	128.353	128.353	128.353
Total circumferential stress			172.321	183.987	193.101	174.375	115.48	140.688	147.017	112.185
Primary membrane circumferential stress*			178.154	178.154	183.738	183.738	128.084	128.084	129.601	129.601
3C*	N_x / (P / R_m)	1.3466	0.49	0.49	0.49	0.49	0	0	0	0
4C*	N_x / (P / R_m)	1.5144	0	0	0	0	0.552	0.552	0.552	0.552
1C-1	M_x / P	0.1285	2.441	-2.441	2.441	-2.441	0	0	0	0
2C	M_x / P	0.0915	0	0	0	0	1.737	-1.737	1.737	-1.737
4A*	N_x / [M_c / (R_m^2*β)]	0.4027	0	0	0	0	-1.2	-1.2	1.2	1.2
2A	M_x / [M_c / (R_m*β)]	0.0578	0	0	0	0	-8.949	8.949	8.949	-8.949
4B*	N_x / [M_L / (R_m^2*β)]	0.2605	-0.772	-0.772	0.772	0.772	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0786	-12.162	12.162	12.162	-12.162	0	0	0	0
Pressure stress*			64.176	64.176	64.176	64.176	90.197	90.197	90.197	90.197
Total longitudinal stress			54.172	73.615	80.041	50.835	82.337	96.761	102.635	81.262
Primary membrane longitudinal stress*			63.894	63.894	65.438	65.438	89.549	89.549	91.948	91.948
Shear from M_t			2.179	2.179	2.179	2.179	2.179	2.179	2.179	2.179
Circ shear from V_c			0.414	0.414	-0.414	-0.414	0	0	0	0
Long shear from V_L			0	0	0	0	-0.414	-0.414	0.414	0.414
Total Shear stress			2.592	2.592	1.765	1.765	1.765	1.765	2.592	2.592
Combined stress (P_L+P_b+Q)			172.376	184.049	193.129	174.403	115.577	140.756	147.169	112.398

Note: * denotes primary stress.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 7{,}999.13 / 1000*76.16 / (2*6.6) - -5{,}589 / (\pi*(84.14^2 - 76.16^2)) + 4{,}737{,}614.3*84.14 / 1.2929E+07$
= 78.37 MPa

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 118 MPa)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (4{,}609^2 + 4{,}609^2)^{0.5} / (\pi*76.16*7.97)$
= 3.417 MPa

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 4{,}070 / (2*\pi*76.16^2*7.97)$

= 14.005 MPa

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 3.417 + 14.005
= 17.422 MPa

UG-45: The total combined shear stress (17.422 MPa) ≤ allowable (0.7*S_n = 0.7*118 = 82.6 MPa)

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (cm^2) For P = 9,025.34 kPa @ 25 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
35.6209	35.6214	1.6819	4.1432	2.4395	24.8768	2.48	6.22	9.6

UG-41 Weld Failure Path Analysis Summary (N) 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
471,400	414,756	697,239	189,808	1,581,482	533,107	1,346,795

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.7	weld size is adequate
Pad to shell fillet (Leg_{42})	9.5	9.8	weld size is adequate
Nozzle to pad groove (Upper)	7.68	20	weld size is adequate

Calculations for internal pressure 9,025.34 kPa @ 25 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(146.33, 73.16 + (10.97 - 0) + (25 - 0))
= 146.33 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(25 - 0), 2.5*(10.97 - 0) + 20)
= 47.43 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(13, 2.5*(25 - 0), 2.5*(10.97 - 0 - 0))
= 13 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 9,025.3415*73.16 / (118,000*1 - 0.6*9,025.3415)
= 5.86 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 9,025.3415*350 / (138,000*1 - 0.6*9,025.3415)
= 23.83 mm

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

t_r = P*R / (S*E - 0.6*P)
= 9,025.3415*350 / (138,000*1 - 0.6*9,025.3415)
= 23.83 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (146.33*23.83*1 + 2*10.97*23.83*1*(1 - 0.8551)) / 100
= 35.6209 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.6819 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (146.33*(1*25 - 1*23.83) - 2*10.97*(1*25 - 1*23.83)*(1 - 0.8551)) / 100
= 1.6819 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(25 + 10.97)*(1*25 - 1*23.83) - 2*10.97*(1*25 - 1*23.83)*(1 - 0.8551)) / 100
= 0.8077 cm^2

A_2 = smaller of the following= 4.1432 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(10.97 - 5.86)*0.8551*25) / 100
= 5.46 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(10.97 - 5.86)*(2.5*10.97 + 20)*0.8551) / 100
= 4.1432 cm^2

A_3 = smaller of the following= 2.4395 cm^2

= $5*t*t_i*f_{r2}$
= (5*25*10.97*0.8551) / 100
= 11.7286 cm^2

= $5*t_i*t_i*f_{r2}$
= (5*10.97*10.97*0.8551) / 100
= 5.1478 cm^2

= $2*h*t_i*f_{r2}$
= (2*13*10.97*0.8551) / 100
= 2.4395 cm^2

A_{41} = Leg^2*f_{r3}
= $(11^2*0.8551) / 100$
= 1.0348 cm^2

A_{42} = Leg^2*f_{r4}
= $(0^2*1) / 100$
= 0 cm^2

(Part of the weld is outside of the limits)

A_{43} = Leg^2*f_{r2}
= $(13^2*0.8551) / 100$
= 1.4452 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((292.66 - 146.33 - 2*10.97)*20*1) / 100
= 24.8768 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 1.6819 + 4.1432 + 2.4395 + 1.0348 + 0 + 1.4452 + 24.8768
= 35.6214 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10.97 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 19 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 9.5 mm

$t_{w(actual)}$ = 0.7*Leg = 0.7*14 = 9.8 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 9,025.3415*73.16 / (118,000*1 - 0.6*9,025.3415) + 0
= 5.86 mm

$t_{a\ UG\text{-}22}$ = 4.83 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[5.86 , 4.83]
= 5.86 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 9,025.3415*350 / (138,000*1 - 0.6*9,025.3415) + 0
= 23.83 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[23.83 , 1.5]
= 23.83 mm

t_b = min[t_{b3} , t_{b1}]
= min[6.22 , 23.83]
= 6.22 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[5.86 , 6.22]
= 6.22 mm

Available nozzle wall thickness new, t_n = 0.875*10.97 = 9.6 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa
Lower fillet weld in shear:	0.49*118 =	57.82 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*168.28*11*57.82 = 168,116.49 N

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*318.28*14*67.62 = 473,288.18 N

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*157.3*10.97*82.6 = 223,950.61 N

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*168.28*25*102.12 = 674,823.73 N

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*168.28*13*57.82 = 198,683.12 N

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*168.28*20*102.12 = 539,858.98 N

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (3,562.0894 - 168.1932 + 2*10.97*0.8551*(1*25 - 1*23.83))*138
= 471,400.07 N

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (414.3218 + 2,487.676 + 103.4837 + 0)*138
= 414,756.49 N

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (414.3218 + 243.9539 + 103.4837 + 144.5158 + 2*10.97*25*0.8551)*138
= 189,807.6 N

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (414.3218 + 243.9539 + 2,487.676 + 103.4837 + 0 + 144.5158 + 2*10.97*25*0.8551)*138
= 533,106.93 N

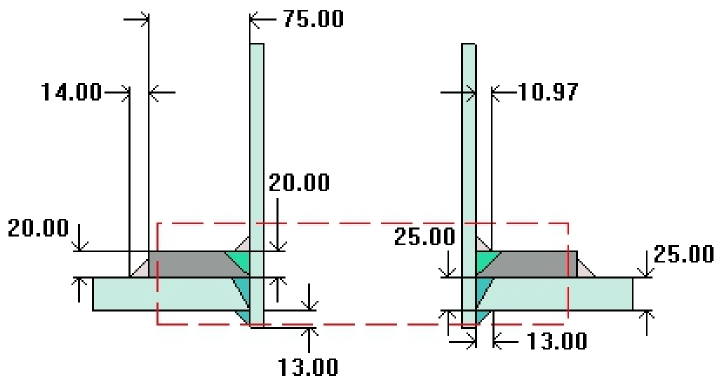
Load for path 1-1 lesser of W or W_{1-1} = 414,756.49 N
Path 1-1 through (2) & (3) = 473,288.18 + 223,950.61 = 697,238.79 N
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 189,807.6 N
Path 2-2 through (1), (4), (5), (6) = 168,116.49 + 674,823.73 + 198,683.12 + 539,858.98 = 1,581,482.32 N
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} = 471,400.07 N
Path 3-3 through (2), (4), (5) = 473,288.18 + 674,823.73 + 198,683.12 = 1,346,795.03 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

6" Two Nozzles (N4 A/B)

ASME Section VIII Division 1, 2013 Edition Metric



$t_{w(lower)}$ = 25 mm
Leg_{41} = 10.97 mm
$t_{w(upper)}$ = 20 mm
Leg_{42} = 14 mm
Leg_{43} = 13 mm
h_{new} = 13 mm
D_p = 318.28 mm
t_e = 20 mm

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

Location and Orientation

Located on:	Shell #1
Orientation:	180°
Nozzle center line offset to datum line:	2,672 mm
End of nozzle to shell center:	625 mm
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 14, ln. 19)
Description:	NPS 6 Sch 80 (XS) DN 150
Inside diameter, new:	146.33 mm
Nominal wall thickness:	10.97 mm
Corrosion allowance:	3 mm
Projection available outside vessel, Lpr:	126.3 mm
Internal projection, h_{new}:	13 mm
Projection available outside vessel to flange face, Lf:	250 mm
Local vessel minimum thickness:	25 mm
Liquid static head included:	0 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 22, ln. 6)
Diameter:	318.28 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 6 Class 600 WN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 352, ln. 31)

Blind included:	No
Rated MDMT:	-41.28°C per UCS-66(b)(1)(b)
Liquid static head:	0 kPa
MAWP rating:	9,530.01 kPa @ 85°C
MAP rating:	10,210.01 kPa @ 25°C
Hydrotest rating:	15,400.02 kPa @ 25°C
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2) For P = 7,998.49 kPa @ 85 °C The opening is adequately reinforced							**UG-45 Nozzle Wall Thickness Summary (mm)** The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
32.7791	32.7795	1.2045	1.769	0.8504	27.2768	1.6787	9.22	9.6

UG-41 Weld Failure Path Analysis Summary (N) 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
437,240	415,041	639,113	100,711	1,434,588	477,130	1,200,316

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	5.58	7.68	weld size is adequate
Pad to shell fillet (Leg_{42})	9.5	9.8	weld size is adequate
Nozzle to pad groove (Upper)	5.58	20	weld size is adequate

WRC 107												
Load Case	P (kPa)	P_r (N)	M_c (N-m)	V_c (N)	M_L (N-m)	V_L (N)	M_t (N-m)	Max Comb Stress (MPa)	Allow Comb Stress (MPa)	Max Local Primary Stress (MPa)	Allow Local Primary Stress (MPa)	Over stressed
Load case 1	7,998.49	5,589	3,350	4,609	3,350	4,609	4,070	188.489	414	182.628	207	No
Load case 1 (Hot Shut Down)	0	5,589	3,350	4,609	3,350	4,609	4,070	-29.227	414	-6.391	207	No
Load case 1 (Pr Reversed)	7,998.49	-5,589	3,350	4,609	3,350	4,609	4,070	**193.122**	**414**	**183.731**	**207**	No
Load case 1 (Pr Reversed) (Hot Shut Down)	0	-5,589	3,350	4,609	3,350	4,609	4,070	29.413	414	6.391	207	No

Calculations for internal pressure 7,998.49 kPa @ 85 °C

Fig UCS-66.2 general note (1) applies.

Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -28.75 °C
Fig UCS-66.1M MDMT reduction = 10.6 °C, (coincident ratio = 0.8113).

Pad is impact test exempt per UG-20(f).

Nozzle UCS-66 governing thk:	9.6 mm
Nozzle rated MDMT:	-39.35 °C
Pad UCS-66 governing thickness:	20 mm
Pad rated MDMT:	-29 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(152.33, 76.16 + (10.97 - 3) + (25 - 3))
= 152.33 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(25 - 3), 2.5*(10.97 - 3) + 20)
= 39.93 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(10, 2.5*(25 - 3), 2.5*(10.97 - 3 - 3))
= 10 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 7,998.4898*76.16 / (118,000*1 - 0.6*7,998.4898)
= 5.38 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 7,998.4898*353 / (138,000*1 - 0.6*7,998.4898)
= 21.2 mm

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

t_r = P*R / (S*E - 0.6*P)
= 7,998.4898*353 / (138,000*1 - 0.6*7,998.4898)
= 21.2 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

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

= $(152.33*21.2*1 + 2*7.97*21.2*1*(1 - 0.8551)) / 100$
= 32.7791 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.2045 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(152.33*(1*22 - 1*21.2) - 2*7.97*(1*22 - 1*21.2)*(1 - 0.8551)) / 100$
= 1.2045 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(2*(22 + 7.97)*(1*22 - 1*21.2) - 2*7.97*(1*22 - 1*21.2)*(1 - 0.8551)) / 100$
= 0.4626 cm^2

A_2 = smaller of the following= 1.769 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $(5*(7.97 - 5.38)*0.8551*22) / 100$
= 2.4368 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $(2*(7.97 - 5.38)*(2.5*7.97 + 20)*0.8551) / 100$
= 1.769 cm^2

A_3 = smaller of the following= 0.8504 cm^2

= $5*t*t_i*f_{r2}$
= $(5*22*4.97*0.8551) / 100$
= 4.6775 cm^2

= $5*t_i*t_i*f_{r2}$
= $(5*4.97*4.97*0.8551) / 100$
= 1.0573 cm^2

= $2*h*t_i*f_{r2}$
= $(2*10*4.97*0.8551) / 100$
= 0.8504 cm^2

A_{41} = Leg^2*f_{r3}
= $(10.97^2*0.8551) / 100$
= 1.0297 cm^2

A_{42} = Leg^2*f_{r4}
= $(0^2*1) / 100$
= 0 cm^2

(Part of the weld is outside of the limits)

A_{43} = Leg^2*f_{r2}
= $(8.71^2*0.8551) / 100$
= 0.649 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((304.66 - 152.33 - 2*7.97)*20*1) / 100
= 27.2768 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 1.2045 + 1.769 + 0.8504 + 1.0297 + 0 + 0.649 + 27.2768
= 32.7795 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 7.97 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 5.58 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*10.97 = 7.68 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 19 mm
$t_{w(min)}$ = 0.5*t_{min} = 9.5 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*14 = 9.8 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 7,998.4898*76.16 / (118,000*1 - 0.6*7,998.4898) + 3
= 8.38 mm

$t_{a\ UG-22}$ = 7.34 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[8.38 , 7.34]
= 8.38 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 7,998.4898*353 / (138,000*1 - 0.6*7,998.4898) + 3
= 24.2 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[24.2 , 4.5]
= 24.2 mm

t_b = min[t_{b3} , t_{b1}]

$= \min[9.22, 24.2]$

$= 9.22$ mm

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

$= \max[8.38, 9.22]$

$= 9.22$ mm

Available nozzle wall thickness new, $t_n = 0.875*10.97 = 9.6$ mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa
Lower fillet weld in shear:	0.49*118 =	57.82 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)*\text{Nozzle OD}*\text{Leg}*S_i = (\pi / 2)*168.28*10.97*57.82 = 167{,}700.78$ N

(2) Outer fillet weld in shear
$(\pi / 2)*\text{Pad OD}*\text{Leg}*S_o = (\pi / 2)*318.28*14*67.62 = 473{,}288.18$ N

(3) Nozzle wall in shear
$(\pi / 2)*\text{Mean nozzle dia}*t_n*S_n = (\pi / 2)*160.3*7.97*82.6 = 165{,}825.13$ N

(4) Groove weld in tension
$(\pi / 2)*\text{Nozzle OD}*t_w*S_g = (\pi / 2)*168.28*22*102.12 = 593{,}844.88$ N

(5) Lower fillet weld in shear
$(\pi / 2)*\text{Nozzle OD}*\text{Leg}*S_l = (\pi / 2)*168.28*8.71*57.82 = 133{,}183.19$ N

(6) Upper groove weld in tension
$(\pi / 2)*\text{Nozzle OD}*t_w*S_g = (\pi / 2)*168.28*20*102.12 = 539{,}858.98$ N

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$

$= (3{,}277.9119 - 120.4514 + 2*7.97*0.8551*(1*22 - 1*21.2))*138$

$= 437{,}240.45$ N

$W_{1\text{-}1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$

$= (176.9029 + 2{,}727.676 + 102.9675 + 0)*138$

$= 415{,}041.45$ N

$W_{2\text{-}2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$

$=$ (176.9029 + 85.0448 + 102.9675 + 64.9031 + 2*7.97*22*0.8551)*138

$=$ 100,711.06 N

$W_{3\text{-}3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$

$=$ (176.9029 + 85.0448 + 2,727.676 + 102.9675 + 0 + 64.9031 + 2*7.97*22*0.8551)*138

$=$ 477,130.39 N

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 415,041.45 N
Path 1-1 through (2) & (3) = 473,288.18 + 165,825.13 = 639,113.31 N
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 100,711.06 N
Path 2-2 through (1), (4), (5), (6) = 167,700.78 + 593,844.88 + 133,183.19 + 539,858.98 = 1,434,587.84 N
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or $W_{3\text{-}3}$ = 437,240.45 N
Path 3-3 through (2), (4), (5) = 473,288.18 + 593,844.88 + 133,183.19 = 1,200,316.25 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1 (Pr Reversed)

Applied Loads

Radial load:	P_r =	-5,589	N
Circumferential moment:	M_c =	3,350	N-m
Circumferential shear:	V_c =	4,609	N
Longitudinal moment:	M_L =	3,350	N-m
Longitudinal shear:	V_L =	4,609	N
Torsion moment:	M_t =	4,070	N-m
Internal pressure:	P =	7,998.49	kPa
Mean shell radius:	R_m =	364	mm
Local shell thickness:	T =	22	mm
Shell yield stress:	S_y =	242	MPa
Design factor:		3	

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 364 / 22 = 16.5455$

$\beta = 0.875*r_o / R_m = 0.875*159.14 / 364 = 0.3825$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =128.339 MPa

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =64.17 MPa

Maximum combined stress (P_L+P_b+Q) = 157.55 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 134.35 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107

Figure	value		A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	$N_\phi / (P / R_m)$	1.2801	0	0	0	0	0.896	0.896	0.896	0.896
4C*	$N_\phi / (P / R_m)$	2.0646	1.441	1.441	1.441	1.441	0	0	0	0
1C	M_ϕ / P	0.0559	0	0	0	0	3.875	-3.875	3.875	-3.875
2C-1	M_ϕ / P	0.0238	1.648	-1.648	1.648	-1.648	0	0	0	0
3A*	$N_\phi / [M_c / (R_m^2 * \beta)]$	0.7066	0	0	0	0	-2.124	-2.124	2.124	2.124
1A	$M_\phi / [M_c / (R_m * \beta)]$	0.0747	0	0	0	0	-22.277	22.277	22.277	-22.277
3B*	$N_\phi / [M_L / (R_m^2 * \beta)]$	1.5212	-4.571	-4.571	4.571	4.571	0	0	0	0
1B-1	$M_\phi / [M_L / (R_m * \beta)]$	0.0201	-5.992	5.992	5.992	-5.992	0	0	0	0
Pressure stress*			128.339	128.339	128.339	128.339	128.339	128.339	128.339	128.339
Total circumferential stress			120.865	129.552	141.991	126.712	108.71	145.514	157.511	105.207
Primary membrane circumferential stress*			125.209	125.209	134.351	134.351	127.112	127.112	131.359	131.359
3C*	$N_x / (P / R_m)$	1.2801	0.896	0.896	0.896	0.896	0	0	0	0
4C*	$N_x / (P / R_m)$	2.0646	0	0	0	0	1.441	1.441	1.441	1.441
1C-1	M_x / P	0.0462	3.199	-3.199	3.199	-3.199	0	0	0	0
2C	M_x / P	0.03	0	0	0	0	2.075	-2.075	2.075	-2.075
4A*	$N_x / [M_c / (R_m^2 * \beta)]$	1.6475	0	0	0	0	-4.95	-4.95	4.95	4.95
2A	$M_x / [M_c / (R_m * \beta)]$	0.0355	0	0	0	0	-10.59	10.59	10.59	-10.59
4B*	$N_x / [M_L / (R_m^2 * \beta)]$	0.6875	-2.068	-2.068	2.068	2.068	0	0	0	0
2B-1	$M_x / [M_L / (R_m * \beta)]$	0.0351	-10.466	10.466	10.466	-10.466	0	0	0	0
Pressure stress*			64.17	64.17	64.17	64.17	64.17	64.17	64.17	64.17
Total longitudinal stress			55.73	70.264	80.8	53.469	52.145	69.175	83.227	57.895
Primary membrane longitudinal stress*			62.997	62.997	67.134	67.134	60.66	60.66	70.561	70.561
Shear from M_t			1.165	1.165	1.165	1.165	1.165	1.165	1.165	1.165
Circ shear from V_c			0.421	0.421	-0.421	-0.421	0	0	0	0
Long shear from V_L			0	0	0	0	-0.421	-0.421	0.421	0.421
Total Shear stress			1.586	1.586	0.745	0.745	0.745	0.745	1.586	1.586
Combined stress (P_L+P_b+Q)			120.906	129.594	141.998	126.719	108.717	145.521	157.545	105.262

Note: * denotes primary stress.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 364 / 42 = 8.6667$

$\beta = 0.875 * r_o / R_m = 0.875 * 84.14 / 364 = 0.2023$

Pressure stress intensity factor, I = 1.4056 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I * P * R_i / T$ =180.388 MPa

Local longitudinal pressure stress = $I * P * R_i / (2 * T)$ =90.197 MPa

Maximum combined stress ($P_L + P_b + Q$) = 193.12 MPa
Allowable combined stress ($P_L + P_b + Q$) = +-3*S = +-414 MPa

The maximum combined stress ($P_L + P_b + Q$) is within allowable limits.

Maximum local primary membrane stress (P_L) = 183.73 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	N_ϕ / (P / R_m)	1.3466	0	0	0	0	0.49	0.49	0.49	0.49
4C*	N_ϕ / (P / R_m)	1.5144	0.552	0.552	0.552	0.552	0	0	0	0
1C	M_ϕ / P	0.1266	0	0	0	0	2.406	-2.406	2.406	-2.406
2C-1	M_ϕ / P	0.0927	1.765	-1.765	1.765	-1.765	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.2537	0	0	0	0	-0.758	-0.758	0.758	0.758
1A	M_ϕ / [M_c / (R_m*β)]	0.097	0	0	0	0	-15.01	15.01	15.01	-15.01
3B*	N_ϕ / [M_L / (R_m^2*β)]	0.9373	-2.792	-2.792	2.792	2.792	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0491	-7.598	7.598	7.598	-7.598	0	0	0	0
Pressure stress*			180.388	180.388	180.388	180.388	128.339	128.339	128.339	128.339
Total circumferential stress			172.314	183.98	193.095	174.368	115.467	140.674	147.003	112.171
Primary membrane circumferential stress*			178.147	178.147	183.731	183.731	128.07	128.07	129.587	129.587
3C*	N_x / (P / R_m)	1.3466	0.49	0.49	0.49	0.49	0	0	0	0
4C*	N_x / (P / R_m)	1.5144	0	0	0	0	0.552	0.552	0.552	0.552
1C-1	M_x / P	0.1285	2.441	-2.441	2.441	-2.441	0	0	0	0
2C	M_x / P	0.0915	0	0	0	0	1.737	-1.737	1.737	-1.737
4A*	N_x / [M_c / (R_m^2*β)]	0.4027	0	0	0	0	-1.2	-1.2	1.2	1.2
2A	M_x / [M_c / (R_m*β)]	0.0578	0	0	0	0	-8.949	8.949	8.949	-8.949
4B*	N_x / [M_L / (R_m^2*β)]	0.2605	-0.772	-0.772	0.772	0.772	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0786	-12.162	12.162	12.162	-12.162	0	0	0	0
Pressure stress*			64.17	64.17	64.17	64.17	90.197	90.197	90.197	90.197
Total longitudinal stress			54.165	73.608	80.034	50.828	82.337	96.761	102.635	81.262
Primary membrane longitudinal stress*			63.887	63.887	65.431	65.431	89.549	89.549	91.948	91.948
Shear from M_t			2.179	2.179	2.179	2.179	2.179	2.179	2.179	2.179
Circ shear from V_c			0.414	0.414	-0.414	-0.414	0	0	0	0
Long shear from V_L			0	0	0	0	-0.414	-0.414	0.414	0.414
Total Shear stress			2.592	2.592	1.765	1.765	1.765	1.765	2.592	2.592
Combined stress (P_L+P_b+Q)			172.369	184.042	193.122	174.396	115.563	140.743	147.155	112.385

Note: * denotes primary stress.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 7{,}998.49 / 1000*76.16 / (2*6.6) - -5{,}589 / (\pi*(84.14^2 - 76.16^2)) + 4{,}737{,}614.3*84.14 / 1.2929E+07$
= 78.366 MPa

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 118 MPa)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (4{,}609^2 + 4{,}609^2)^{0.5} / (\pi*76.16*7.97)$
= 3.417 MPa

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 4{,}070 / (2*\pi*76.16^2*7.97)$

= 14.005 MPa

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 3.417 + 14.005
= 17.422 MPa

UG-45: The total combined shear stress (17.422 MPa) ≤ allowable (0.7*S_n = 0.7*118 = 82.6 MPa)

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (cm^2) For P = 9,024.71 kPa @ 25 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
35.6182	35.6189	1.6845	4.1432	2.4395	24.8768	2.4748	6.22	9.6

UG-41 Weld Failure Path Analysis Summary (N) 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
471,332	414,685	697,239	189,736	1,581,067	533,036	1,346,795

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.68	weld size is adequate
Pad to shell fillet (Leg_{42})	9.5	9.8	weld size is adequate
Nozzle to pad groove (Upper)	7.68	20	weld size is adequate

Calculations for internal pressure 9,024.71 kPa @ 25 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(146.33, 73.16 + (10.97 - 0) + (25 - 0))
= 146.33 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(25 - 0), 2.5*(10.97 - 0) + 20)
= 47.43 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(13, 2.5*(25 - 0), 2.5*(10.97 - 0 - 0))
= 13 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 9,024.7063*73.16 / (118,000*1 - 0.6*9,024.7063)
= 5.86 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 9,024.7063*350 / (138,000*1 - 0.6*9,024.7063)
= 23.82 mm

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

t_r = P*R / (S*E - 0.6*P)
= 9,024.7063*350 / (138,000*1 - 0.6*9,024.7063)
= 23.82 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (146.33*23.82*1 + 2*10.97*23.82*1*(1 - 0.8551)) / 100
= 35.6182 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.6845 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (146.33*(1*25 - 1*23.82) - 2*10.97*(1*25 - 1*23.82)*(1 - 0.8551)) / 100
= 1.6845 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(25 + 10.97)*(1*25 - 1*23.82) - 2*10.97*(1*25 - 1*23.82)*(1 - 0.8551)) / 100
= 0.809 cm^2

A_2 = smaller of the following= 4.1432 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(10.97 - 5.86)*0.8551*25) / 100
= 5.46 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(10.97 - 5.86)*(2.5*10.97 + 20)*0.8551) / 100
= 4.1432 cm^2

A_3 = smaller of the following= 2.4395 cm^2

= $5*t*t_i*f_{r2}$
= (5*25*10.97*0.8551) / 100
= 11.7286 cm^2

= $5*t_i*t_i*f_{r2}$
= (5*10.97*10.97*0.8551) / 100
= 5.1478 cm^2

= $2*h*t_i*f_{r2}$
= (2*13*10.97*0.8551) / 100
= 2.4395 cm^2

A_{41} = Leg^2*f_{r3}
= $(10.97^2*0.8551) / 100$
= 1.0297 cm^2

A_{42} = Leg^2*f_{r4}
= $(0^2*1) / 100$
= 0 cm^2

(Part of the weld is outside of the limits)

A_{43} = Leg^2*f_{r2}
= $(13^2*0.8551) / 100$
= 1.4452 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((292.66 - 146.33 - 2*10.97)*20*1) / 100
= 24.8768 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 1.6845 + 4.1432 + 2.4395 + 1.0297 + 0 + 1.4452 + 24.8768
= 35.6189 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10.97 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*10.97 = 7.68 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 19 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 9.5 mm

$t_{w(actual)}$ = 0.7*Leg = 0.7*14 = 9.8 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 9,024.7063*73.16 / (118,000*1 - 0.6*9,024.7063) + 0
= 5.86 mm

$t_{a\ UG\text{-}22}$ = 4.83 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[5.86 , 4.83]
= 5.86 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 9,024.7063*350 / (138,000*1 - 0.6*9,024.7063) + 0
= 23.82 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[23.82 , 1.5]
= 23.82 mm

t_b = min[t_{b3} , t_{b1}]
= min[6.22 , 23.82]
= 6.22 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[5.86 , 6.22]
= 6.22 mm

Available nozzle wall thickness new, t_n = 0.875*10.97 = 9.6 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa
Lower fillet weld in shear:	0.49*118 =	57.82 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*168.28*10.97*57.82 = 167,700.78 N

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*318.28*14*67.62 = 473,288.18 N

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*157.3*10.97*82.6 = 223,950.61 N

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*168.28*25*102.12 = 674,823.73 N

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*168.28*13*57.82 = 198,683.12 N

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*168.28*20*102.12 = 539,858.98 N

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (3,561.8236 - 168.4513 + 2*10.97*0.8551*(1*25 - 1*23.82))*138
= 471,332.38 N

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (414.3218 + 2,487.676 + 102.9675 + 0)*138
= 414,685.26 N

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (414.3218 + 243.9539 + 102.9675 + 144.5158 + 2*10.97*25*0.8551)*138
= 189,736.37 N

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (414.3218 + 243.9539 + 2,487.676 + 102.9675 + 0 + 144.5158 + 2*10.97*25*0.8551)*138
= 533,035.7 N

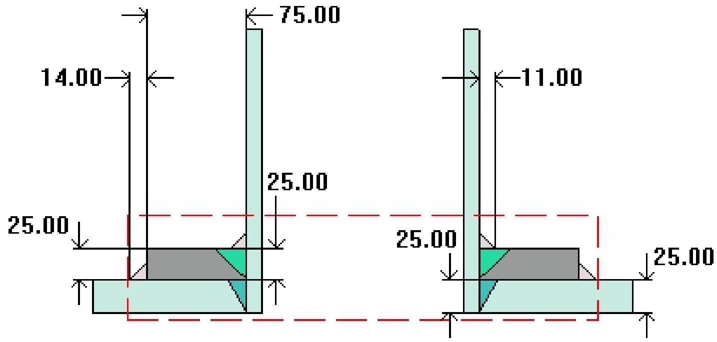
Load for path 1-1 lesser of W or W_{1-1} = 414,685.26 N
Path 1-1 through (2) & (3) = 473,288.18 + 223,950.61 = 697,238.79 N
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 189,736.37 N
Path 2-2 through (1), (4), (5), (6) = 167,700.78 + 674,823.73 + 198,683.12 + 539,858.98 = 1,581,066.61 N
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} = 471,332.38 N
Path 3-3 through (2), (4), (5) = 473,288.18 + 674,823.73 + 198,683.12 = 1,346,795.03 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

8" Two Nozzles (N1 A/B)

ASME Section VIII Division 1, 2013 Edition Metric



$t_{w(lower)}$ = 25 mm
Leg_{41} = 11 mm
$t_{w(upper)}$ = 25 mm
Leg_{42} = 14 mm
D_p = 369.08 mm
t_e = 25 mm

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

Location and Orientation

Located on:	Front Channel
Orientation:	0°
Nozzle center line offset to datum line:	13,253.29 mm
End of nozzle to shell center:	650 mm
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 14, ln. 19)
Description:	NPS 8 Sch 80 (XS) DN 200
Inside diameter, new:	193.68 mm
Nominal wall thickness:	12.7 mm
Corrosion allowance:	3 mm
Projection available outside vessel, Lpr:	135.3 mm
Projection available outside vessel to flange face, Lf:	275 mm
Local vessel minimum thickness:	25 mm
Liquid static head included:	0 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 22, ln. 6)
Diameter:	369.08 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 8 Class 600 WN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 352, ln. 31)
Blind included:	No

Rated MDMT:	-41.5°C per UCS-66(b)(1)(b)
Liquid static head:	0 kPa
MAWP rating:	9,530.01 kPa @ 85°C
MAP rating:	10,210.01 kPa @ 25°C
Hydrotest rating:	15,400.02 kPa @ 25°C
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2) For P = 8,116.25 kPa @ 85 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
43.5757	43.5768	0.9445	2.1374	--	37.5	2.9948	10.16	11.11

UG-41 Weld Failure Path Analysis Summary (N) 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
589,409	588,325	812,346	94,143	1,870,541	638,691	1,321,958

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.7	weld size is adequate
Pad to shell fillet (Leg_{42})	9.5	9.8	weld size is adequate
Nozzle to pad groove (Upper)	6.79	25	weld size is adequate

WRC 107												
Load Case	P (kPa)	P_r (N)	M_c (N-m)	V_c (N)	M_L (N-m)	V_L (N)	M_t (N-m)	Max Comb Stress (MPa)	Allow Comb Stress (MPa)	Max Local Primary Stress (MPa)	Allow Local Primary Stress (MPa)	Over stressed
Load case 1	8,116.25	7,158	6,820	5,883	6,820	5,883	8,220	210.883	414	203.892	207	No
Load case 1 (Hot Shut Down)	0	7,158	6,820	5,883	6,820	5,883	8,220	-46.56	414	-10.887	207	No
Load case 1 (Pr Reversed)	8,116.25	-7,158	6,820	5,883	6,820	5,883	8,220	**214.896**	**414**	**204.981**	**207**	No
Load case 1 (Pr Reversed) (Hot Shut Down)	0	-7,158	6,820	5,883	6,820	5,883	8,220	46.767	414	10.887	207	No

Calculations for internal pressure 8,116.25 kPa @ 85 °C

Fig UCS-66.2 general note (1) applies.

Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -24.98 °C
Fig UCS-66.1M MDMT reduction = 7.8 °C, (coincident ratio = 0.8614).

Pad is impact test exempt per UG-20(f).

Nozzle UCS-66 governing thk:	11.11 mm
Nozzle rated MDMT:	-32.78 °C
Pad UCS-66 governing thickness:	25 mm
Pad rated MDMT:	-29 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(199.67, 99.84 + (12.7 - 3) + (25 - 3))
= 199.67 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(25 - 3), 2.5*(12.7 - 3) + 25)
= 49.25 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 8,116.2485*99.84 / (118,000*1 - 0.6*8,116.2485)
= 7.16 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 8,116.2485*353 / (138,000*1 - 0.6*8,116.2485)
= 21.52 mm

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

t_r = P*R / (S*E - 0.6*P)
= 8,116.2485*353 / (138,000*1 - 0.6*8,116.2485)
= 21.52 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})
= (199.67*21.52*1 + 2*9.7*21.52*1*(1 - 0.8551)) / 100
= 43.5757 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.9445 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (199.67*(1*22 - 1*21.52) - 2*9.7*(1*22 - 1*21.52)*(1 - 0.8551)) / 100
= 0.9445 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(22 + 9.7)*(1*22 - 1*21.52) - 2*9.7*(1*22 - 1*21.52)*(1 - 0.8551)) / 100
= 0.291 cm^2

A_2 = smaller of the following= 2.1374 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(9.7 - 7.16)*0.8551*22) / 100
= 2.3871 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(9.7 - 7.16)*(2.5*9.7 + 25)*0.8551) / 100
= 2.1374 cm^2

A_{41} = Leg^2*f_{r3}
= $(11^2*0.8551) / 100$
= 1.0348 cm^2

A_{42} = Leg^2*f_{r4}
= $(14^2*1) / 100$
= 1.96 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((369.08 - 199.67 - 2*9.7)*25*1) / 100
= 37.5 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0.9445 + 2.1374 + 1.0348 + 1.96 + 37.5
= 43.5768 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 9.7 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 19 mm

$t_{w(min)}$ = 0.5*t_{min} = 9.5 mm

$t_{w(actual)}$ = 0.7*Leg = 0.7*14 = 9.8 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 8,116.2485*99.84 / (118,000*1 - 0.6*8,116.2485) + 3
= 10.16 mm

$t_{a\ UG\text{-}22}$ = 8.56 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[10.16 , 8.56]
= 10.16 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 8,116.2485*353 / (138,000*1 - 0.6*8,116.2485) + 3
= 24.52 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[24.52 , 4.5]
= 24.52 mm

t_b = min[t_{b3} , t_{b1}]
= min[10.16 , 24.52]
= 10.16 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[10.16 , 10.16]
= 10.16 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*219.08*11*57.82 = 218,868.63 N

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*369.08*14*67.62 = 548,829.9 N

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*209.37*9.7*82.6 = 263,516.39 N

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*219.08*22*102.12 = 773,127.94 N

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*219.08*25*102.12 = 878,544.1 N

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (4,357.5722 - 94.4514 + 2*9.7*0.8551*(1*22 - 1*21.52))*138
= 589,409.3 N

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (213.7415 + 3,750 + 103.4837 + 195.9996)*138
= 588,325.1 N

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (213.7415 + 0 + 103.4837 + 0 + 2*9.7*22*0.8551)*138
= 94,143.05 N

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (213.7415 + 0 + 3,750 + 103.4837 + 195.9996 + 0 + 2*9.7*22*0.8551)*138
= 638,691.07 N

Load for path 1-1 lesser of W or W_{1-1} = 588,325.1 N
Path 1-1 through (2) & (3) = 548,829.9 + 263,516.39 = 812,346.29 N
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} = 94,143.05 N
Path 2-2 through (1), (4), (6) = 218,868.63 + 773,127.94 + 878,544.1 = 1,870,540.68 N
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} = 589,409.3 N
Path 3-3 through (2), (4) = 548,829.9 + 773,127.94 = 1,321,957.84 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1 (Pr Reversed)

Applied Loads

Radial load:	P_r =	-7,158	N
Circumferential moment:	M_c =	6,820	N-m
Circumferential shear:	V_c =	5,883	N
Longitudinal moment:	M_L =	6,820	N-m
Longitudinal shear:	V_L =	5,883	N
Torsion moment:	M_t =	8,220	N-m
Internal pressure:	P =	8,116.25	kPa
Mean shell radius:	R_m =	364	mm
Local shell thickness:	T =	22	mm
Shell yield stress:	S_y =	242	MPa
Design factor:		3	

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 364 / 22 = 16.5453$

$\beta = 0.875 * r_o / R_m = 0.875 * 184.54 / 364 = 0.4436$

Pressure stress intensity factor, I = 1.0318 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =134.372 MPa

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =67.183 MPa

Maximum combined stress (P_L+P_b+Q) = 176.75 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 143.08 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	1.062	0	0	0	0	0.951	0.951	0.951	0.951
4C*	N_ϕ / (P / R_m)	1.8734	1.675	1.675	1.675	1.675	0	0	0	0
1C	M_ϕ / P	0.0559	0	0	0	0	4.957	-4.957	4.957	-4.957
2C-1	M_ϕ / P	0.0181	1.606	-1.606	1.606	-1.606	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.6594	0	0	0	0	-3.475	-3.475	3.475	3.475
1A	M_ϕ / [M_c / (R_m*β)]	0.0708	0	0	0	0	-37.073	37.073	37.073	-37.073
3B*	N_ϕ / [M_L / (R_m^2*β)]	1.334	-7.033	-7.033	7.033	7.033	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.016	-8.377	8.377	8.377	-8.377	0	0	0	0
Pressure stress*			134.372	134.372	134.372	134.372	130.228	130.228	130.228	130.228
Total circumferential stress			122.244	135.785	153.064	133.096	95.589	159.82	176.685	92.624
Primary membrane circumferential stress*			129.015	129.015	143.08	143.08	127.705	127.705	134.655	134.655
3C*	N_x / (P / R_m)	1.062	0.951	0.951	0.951	0.951	0	0	0	0
4C*	N_x / (P / R_m)	1.8734	0	0	0	0	1.675	1.675	1.675	1.675
1C-1	M_x / P	0.0362	3.213	-3.213	3.213	-3.213	0	0	0	0
2C	M_x / P	0.03	0	0	0	0	2.661	-2.661	2.661	-2.661
4A*	N_x / [M_c / (R_m^2*β)]	1.7461	0	0	0	0	-9.211	-9.211	9.211	9.211
2A	M_x / [M_c / (R_m*β)]	0.0332	0	0	0	0	-17.382	17.382	17.382	-17.382
4B*	N_x / [M_L / (R_m^2*β)]	0.6491	-3.427	-3.427	3.427	3.427	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0285	-14.92	14.92	14.92	-14.92	0	0	0	0
Pressure stress*			65.114	65.114	65.114	65.114	67.183	67.183	67.183	67.183
Total longitudinal stress			50.932	74.346	87.625	51.359	44.926	74.367	98.112	58.026
Primary membrane longitudinal stress*			62.639	62.639	69.492	69.492	59.647	59.647	78.069	78.069
Shear from M_t			1.744	1.744	1.744	1.744	1.744	1.744	1.744	1.744
Circ shear from V_c			0.462	0.462	-0.462	-0.462	0	0	0	0
Long shear from V_L			0	0	0	0	-0.462	-0.462	0.462	0.462
Total Shear stress			2.206	2.206	1.282	1.282	1.282	1.282	2.206	2.206
Combined stress (P_L+P_b+Q)			122.313	135.861	153.091	133.117	95.623	159.841	176.747	92.762

Note: * denotes primary stress.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 364 / 47 = 7.7446$

$\beta = 0.875*r_o / R_m = 0.875*109.54 / 364 = 0.2633$

Pressure stress intensity factor, I = 1.541 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = I*P*R_i / T =200.679 MPa

Local longitudinal pressure stress = I*P*R_i / (2*T) =100.339 MPa

Maximum combined stress (P_L+P_b+Q) = 214.9 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 204.98 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	N_ϕ / (P / R_m)	1.1011	0	0	0	0	0.462	0.462	0.462	0.462
4C*	N_ϕ / (P / R_m)	1.2994	0.545	0.545	0.545	0.545	0	0	0	0
1C	M_ϕ / P	0.1044	0	0	0	0	2.027	-2.027	2.027	-2.027
2C-1	M_ϕ / P	0.0753	1.462	-1.462	1.462	-1.462	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.2717	0	0	0	0	-1.131	-1.131	1.131	1.131
1A	M_ϕ / [M_c / (R_m*β)]	0.095	0	0	0	0	-18.361	18.361	18.361	-18.361
3B*	N_ϕ / [M_L / (R_m^2*β)]	0.9028	-3.758	-3.758	3.758	3.758	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0436	-8.425	8.425	8.425	-8.425	0	0	0	0
Pressure stress*			200.679	200.679	200.679	200.679	130.228	130.228	130.228	130.228
Total circumferential stress			190.502	204.43	214.868	195.094	113.226	145.893	152.209	111.433
Primary membrane circumferential stress*			197.466	197.466	204.981	204.981	129.559	129.559	131.821	131.821
3C*	N_x / (P / R_m)	1.1011	0.462	0.462	0.462	0.462	0	0	0	0
4C*	N_x / (P / R_m)	1.2994	0	0	0	0	0.545	0.545	0.545	0.545
1C-1	M_x / P	0.1043	2.027	-2.027	2.027	-2.027	0	0	0	0
2C	M_x / P	0.075	0	0	0	0	1.455	-1.455	1.455	-1.455
4A*	N_x / [M_c / (R_m^2*β)]	0.469	0	0	0	0	-1.951	-1.951	1.951	1.951
2A	M_x / [M_c / (R_m*β)]	0.0554	0	0	0	0	-10.708	10.708	10.708	-10.708
4B*	N_x / [M_L / (R_m^2*β)]	0.2719	-1.131	-1.131	1.131	1.131	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0707	-13.665	13.665	13.665	-13.665	0	0	0	0
Pressure stress*			65.114	65.114	65.114	65.114	100.339	100.339	100.339	100.339
Total longitudinal stress			52.807	76.084	82.399	51.014	89.68	108.186	114.998	90.673
Primary membrane longitudinal stress*			64.445	64.445	66.707	66.707	98.933	98.933	102.835	102.835
Shear from M_t			2.317	2.317	2.317	2.317	2.317	2.317	2.317	2.317
Circ shear from V_c			0.365	0.365	-0.365	-0.365	0	0	0	0
Long shear from V_L			0	0	0	0	-0.365	-0.365	0.365	0.365
Total Shear stress			2.682	2.682	1.951	1.951	1.951	1.951	2.682	2.682
Combined stress (P_L+P_b+Q)			190.557	204.485	214.896	195.122	113.384	145.996	152.402	111.771

Note: * denotes primary stress.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\,(Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 8{,}116.25 / 1000*99.84 / (2*8.11) - -7{,}158 / (\pi*(109.54^2 - 99.84^2)) + 9{,}644{,}934.2*109.54 / 3.5039E+07$
= 81.214 MPa

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 118 MPa)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (5{,}883^2 + 5{,}883^2)^{0.5} / (\pi*99.84*9.7)$
= 2.735 MPa

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 8{,}220 / (2*\pi*99.84^2*9.7)$

= 13.531 MPa

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 2.735 + 13.531
= 16.265 MPa

UG-45: The total combined shear stress (16.265 MPa) ≤ allowable ($0.7*S_n$ = 0.7*118 = 82.6 MPa)

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (cm^2) For P = 9,048.06 kPa @ 25 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
47.1436	47.1445	2.1135	4.7722	--	37.5	2.7587	7.78	11.11

UG-41 Weld Failure Path Analysis Summary (N) 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
624,749	621,427	888,894	155,070	1,975,957	696,360	1,427,374

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.7	weld size is adequate
Pad to shell fillet (Leg_{42})	9.5	9.8	weld size is adequate
Nozzle to pad groove (Upper)	8.89	25	weld size is adequate

Calculations for internal pressure 9,048.06 kPa @ 25 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(193.68, 96.84 + (12.7 - 0) + (25 - 0))
= 193.68 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(25 - 0), 2.5*(12.7 - 0) + 25)
= 56.75 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 9,048.0631*96.84 / (118,000*1 - 0.6*9,048.0631)
= 7.78 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 9,048.0631*350 / (138,000*1 - 0.6*9,048.0631)

= 23.89 mm

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

t_r = $P*R / (S*E - 0.6*P)$
= $9{,}048.0631*350 / (138{,}000*1 - 0.6*9{,}048.0631)$
= 23.89 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $(193.68*23.89*1 + 2*12.7*23.89*1*(1 - 0.8551)) / 100$
= 47.1436 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 2.1135 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(193.68*(1*25 - 1*23.89) - 2*12.7*(1*25 - 1*23.89)*(1 - 0.8551)) / 100$
= 2.1135 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(2*(25 + 12.7)*(1*25 - 1*23.89) - 2*12.7*(1*25 - 1*23.89)*(1 - 0.8551)) / 100$
= 0.7981 cm^2

A_2 = smaller of the following= 4.7722 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $(5*(12.7 - 7.78)*0.8551*25) / 100$
= 5.2561 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $(2*(12.7 - 7.78)*(2.5*12.7 + 25)*0.8551) / 100$
= 4.7722 cm^2

A_{41} = Leg^2*f_{r3}
= $(11^2*0.8551) / 100$
= 1.0348 cm^2

A_{42} = Leg^2*f_{r4}
= $(13.13^2*1) / 100$
= 1.7239 cm^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((369.08 - 193.68 - 2*12.7)*25*1) / 100
= 37.5 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 2.1135 + 4.7722 + 1.0348 + 1.7239 + 37.5
= 47.1445 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 12.7 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 19 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 9.5 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*14 = 9.8 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 9,048.0631*96.84 / (118,000*1 - 0.6*9,048.0631) + 0
= 7.78 mm

$t_{a\ UG\text{-}22}$ = 6.1 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[7.78 , 6.1]
= 7.78 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 9,048.0631*350 / (138,000*1 - 0.6*9,048.0631) + 0
= 23.89 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[23.89 , 1.5]
= 23.89 mm

t_b = min[t_{b3} , t_{b1}]
= min[7.16 , 23.89]
= 7.16 mm

t_{UG-45} = max[t_a , t_b]
= max[7.78 , 7.16]
= 7.78 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*219.08*11*57.82 = 218,868.63 N

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*369.08*14*67.62 = 548,829.9 N

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*206.38*12.7*82.6 = 340,064.1 N

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*219.08*25*102.12 = 878,544.1 N

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*219.08*25*102.12 = 878,544.1 N

Loading on welds per UG-41(b)(1)

W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v
= (4,714.3649 - 211.3544 + 2*12.7*0.8551*(1*25 - 1*23.89))*138
= 624,749.46 N

W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v
= (477.2249 + 3,750 + 103.4837 + 172.3868)*138
= 621,427.23 N

W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v
= (477.2249 + 0 + 103.4837 + 0 + 2*12.7*25*0.8551)*138
= 155,070.21 N

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (477.2249 + 0 + 3,750 + 103.4837 + 172.3868 + 0 + 2*12.7*25*0.8551)*138
= 696,359.65 N

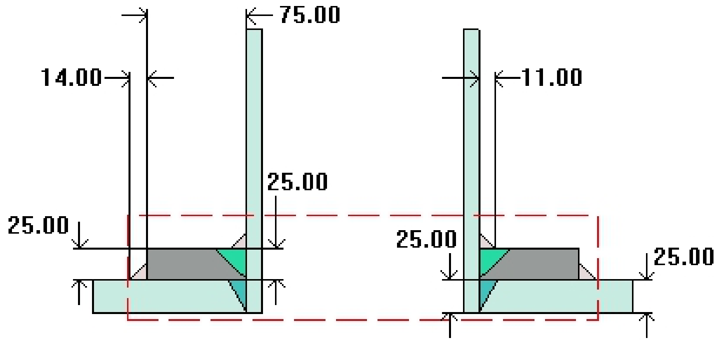
Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 621,427.23 N
Path 1-1 through (2) & (3) = 548,829.9 + 340,064.1 = 888,894 N
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 155,070.21 N
Path 2-2 through (1), (4), (6) = 218,868.63 + 878,544.1 + 878,544.1 = 1,975,956.83 N
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or $W_{3\text{-}3}$ = 624,749.46 N
Path 3-3 through (2), (4) = 548,829.9 + 878,544.1 = 1,427,374 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

8" Two Nozzles (N9)

ASME Section VIII Division 1, 2013 Edition Metric



$t_{w(lower)}$ = 25 mm
Leg_{41} = 11 mm
$t_{w(upper)}$ = 25 mm
Leg_{42} = 14 mm
D_p = 369.08 mm
t_e = 25 mm

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

Location and Orientation

Located on:	Rear Channel
Orientation:	180°
Nozzle center line offset to datum line:	300 mm
End of nozzle to shell center:	650 mm
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 14, ln. 19)
Description:	NPS 8 Sch 80 (XS) DN 200
Inside diameter, new:	193.68 mm
Nominal wall thickness:	12.7 mm
Corrosion allowance:	3 mm
Projection available outside vessel, Lpr:	135.3 mm
Projection available outside vessel to flange face, Lf:	275 mm
Local vessel minimum thickness:	25 mm
Liquid static head included:	0 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 22, ln. 6)
Diameter:	369.08 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 8 Class 600 WN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 352, ln. 31)
Blind included:	No

Rated MDMT:	-41.5°C per UCS-66(b)(1)(b)
Liquid static head:	0 kPa
MAWP rating:	9,530.01 kPa @ 85°C
MAP rating:	10,210.01 kPa @ 25°C
Hydrotest rating:	15,400.02 kPa @ 25°C
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2) For P = 8,116.25 kPa @ 85 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
43.5757	43.5768	0.9445	2.1374	--	37.5	2.9948	10.16	11.11

UG-41 Weld Failure Path Analysis Summary (N) 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
589,409	588,325	812,346	94,143	1,870,541	638,691	1,321,958

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.7	weld size is adequate
Pad to shell fillet (Leg_{42})	9.5	9.8	weld size is adequate
Nozzle to pad groove (Upper)	6.79	25	weld size is adequate

WRC 107												
Load Case	P (kPa)	P_r (N)	M_c (N-m)	V_c (N)	M_L (N-m)	V_L (N)	M_t (N-m)	Max Comb Stress (MPa)	Allow Comb Stress (MPa)	Max Local Primary Stress (MPa)	Allow Local Primary Stress (MPa)	Over stressed
Load case 1	8,116.25	7,158	6,820	5,883	6,820	5,883	8,220	210.883	414	203.892	207	No
Load case 1 (Hot Shut Down)	0	7,158	6,820	5,883	6,820	5,883	8,220	-46.56	414	-10.887	207	No
Load case 1 (Pr Reversed)	8,116.25	-7,158	6,820	5,883	6,820	5,883	8,220	**214.896**	**414**	**204.981**	**207**	No
Load case 1 (Pr Reversed) (Hot Shut Down)	0	-7,158	6,820	5,883	6,820	5,883	8,220	46.767	414	10.887	207	No

Calculations for internal pressure 8,116.25 kPa @ 85 °C

Fig UCS-66.2 general note (1) applies.

Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -24.98 °C
Fig UCS-66.1M MDMT reduction = 7.8 °C, (coincident ratio = 0.8614).

Pad is impact test exempt per UG-20(f).

Nozzle UCS-66 governing thk:	11.11 mm
Nozzle rated MDMT:	-32.78 °C
Pad UCS-66 governing thickness:	25 mm
Pad rated MDMT:	-29 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(199.67, 99.84 + (12.7 - 3) + (25 - 3))
= 199.67 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(25 - 3), 2.5*(12.7 - 3) + 25)
= 49.25 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 8,116.2485*99.84 / (118,000*1 - 0.6*8,116.2485)
= 7.16 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 8,116.2485*353 / (138,000*1 - 0.6*8,116.2485)
= 21.52 mm

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

t_r = P*R / (S*E - 0.6*P)
= 8,116.2485*353 / (138,000*1 - 0.6*8,116.2485)
= 21.52 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})
= (199.67*21.52*1 + 2*9.7*21.52*1*(1 - 0.8551)) / 100
= 43.5757 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.9445 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (199.67*(1*22 - 1*21.52) - 2*9.7*(1*22 - 1*21.52)*(1 - 0.8551)) / 100
= 0.9445 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(22 + 9.7)*(1*22 - 1*21.52) - 2*9.7*(1*22 - 1*21.52)*(1 - 0.8551)) / 100
= 0.291 cm^2

A_2 = smaller of the following= 2.1374 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(9.7 - 7.16)*0.8551*22) / 100
= 2.3871 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(9.7 - 7.16)*(2.5*9.7 + 25)*0.8551) / 100
= 2.1374 cm^2

A_{41} = Leg^2*f_{r3}
= $(11^2*0.8551) / 100$
= 1.0348 cm^2

A_{42} = Leg^2*f_{r4}
= $(14^2*1) / 100$
= 1.96 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((369.08 - 199.67 - 2*9.7)*25*1) / 100
= 37.5 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0.9445 + 2.1374 + 1.0348 + 1.96 + 37.5
= 43.5768 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 9.7 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 19 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 9.5 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*14 = 9.8 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 8,116.2485*99.84 / (118,000*1 - 0.6*8,116.2485) + 3
= 10.16 mm

$t_{a\ UG\text{-}22}$ = 8.56 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[10.16 , 8.56]
= 10.16 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 8,116.2485*353 / (138,000*1 - 0.6*8,116.2485) + 3
= 24.52 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[24.52 , 4.5]
= 24.52 mm

t_b = min[t_{b3} , t_{b1}]
= min[10.16 , 24.52]
= 10.16 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[10.16 , 10.16]
= 10.16 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*219.08*11*57.82 = 218,868.63 N

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*369.08*14*67.62 = 548,829.9 N

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*209.37*9.7*82.6 = 263,516.39 N

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*219.08*22*102.12 = 773,127.94 N

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*219.08*25*102.12 = 878,544.1 N

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (4,357.5722 - 94.4514 + 2*9.7*0.8551*(1*22 - 1*21.52))*138
= 589,409.3 N

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (213.7415 + 3,750 + 103.4837 + 195.9996)*138
= 588,325.1 N

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (213.7415 + 0 + 103.4837 + 0 + 2*9.7*22*0.8551)*138
= 94,143.05 N

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (213.7415 + 0 + 3,750 + 103.4837 + 195.9996 + 0 + 2*9.7*22*0.8551)*138
= 638,691.07 N

Load for path 1-1 lesser of W or W_{1-1} = 588,325.1 N
Path 1-1 through (2) & (3) = 548,829.9 + 263,516.39 = 812,346.29 N
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} = 94,143.05 N
Path 2-2 through (1), (4), (6) = 218,868.63 + 773,127.94 + 878,544.1 = 1,870,540.68 N
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} = 589,409.3 N
Path 3-3 through (2), (4) = 548,829.9 + 773,127.94 = 1,321,957.84 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1 (Pr Reversed)

Applied Loads

Radial load:	P_r =	-7,158	N
Circumferential moment:	M_c =	6,820	N-m
Circumferential shear:	V_c =	5,883	N
Longitudinal moment:	M_L =	6,820	N-m
Longitudinal shear:	V_L =	5,883	N
Torsion moment:	M_t =	8,220	N-m
Internal pressure:	P =	8,116.25	kPa
Mean shell radius:	R_m =	364	mm
Local shell thickness:	T =	22	mm
Shell yield stress:	S_y =	242	MPa
Design factor:		3	

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 364 / 22 = 16.5453$

$\beta = 0.875 * r_o / R_m = 0.875 * 184.54 / 364 = 0.4436$

Pressure stress intensity factor, I = 1.0318 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I * P * R_i / T$ =134.372 MPa

Local longitudinal pressure stress = $I * P * R_i / (2 * T)$ =67.183 MPa

Maximum combined stress ($P_L + P_b + Q$) = 176.75 MPa
Allowable combined stress ($P_L + P_b + Q$) = +-3*S = +-414 MPa

The maximum combined stress ($P_L + P_b + Q$) is within allowable limits.

Maximum local primary membrane stress (P_L) = 143.08 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	N_ϕ / (P / R_m)	1.062	0	0	0	0	0.951	0.951	0.951	0.951
4C*	N_ϕ / (P / R_m)	1.8734	1.675	1.675	1.675	1.675	0	0	0	0
1C	M_ϕ / P	0.0559	0	0	0	0	4.957	-4.957	4.957	-4.957
2C-1	M_ϕ / P	0.0181	1.606	-1.606	1.606	-1.606	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.6594	0	0	0	0	-3.475	-3.475	3.475	3.475
1A	M_ϕ / [M_c / (R_m*β)]	0.0708	0	0	0	0	-37.073	37.073	37.073	-37.073
3B*	N_ϕ / [M_L / (R_m^2*β)]	1.334	-7.033	-7.033	7.033	7.033	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.016	-8.377	8.377	8.377	-8.377	0	0	0	0
Pressure stress*			134.372	134.372	134.372	134.372	130.228	130.228	130.228	130.228
Total circumferential stress			122.244	135.785	153.064	133.096	95.589	159.82	176.685	92.624
Primary membrane circumferential stress*			129.015	129.015	143.08	143.08	127.705	127.705	134.655	134.655
3C*	N_x / (P / R_m)	1.062	0.951	0.951	0.951	0.951	0	0	0	0
4C*	N_x / (P / R_m)	1.8734	0	0	0	0	1.675	1.675	1.675	1.675
1C-1	M_x / P	0.0362	3.213	-3.213	3.213	-3.213	0	0	0	0
2C	M_x / P	0.03	0	0	0	0	2.661	-2.661	2.661	-2.661
4A*	N_x / [M_c / (R_m^2*β)]	1.7461	0	0	0	0	-9.211	-9.211	9.211	9.211
2A	M_x / [M_c / (R_m*β)]	0.0332	0	0	0	0	-17.382	17.382	17.382	-17.382
4B*	N_x / [M_L / (R_m^2*β)]	0.6491	-3.427	-3.427	3.427	3.427	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0285	-14.92	14.92	14.92	-14.92	0	0	0	0
Pressure stress*			65.114	65.114	65.114	65.114	67.183	67.183	67.183	67.183
Total longitudinal stress			50.932	74.346	87.625	51.359	44.926	74.367	98.112	58.026
Primary membrane longitudinal stress*			62.639	62.639	69.492	69.492	59.647	59.647	78.069	78.069
Shear from M_t			1.744	1.744	1.744	1.744	1.744	1.744	1.744	1.744
Circ shear from V_c			0.462	0.462	-0.462	-0.462	0	0	0	0
Long shear from V_L			0	0	0	0	-0.462	-0.462	0.462	0.462
Total Shear stress			2.206	2.206	1.282	1.282	1.282	1.282	2.206	2.206
Combined stress (P_L+P_b+Q)			122.313	135.861	153.091	133.117	95.623	159.841	176.747	92.762

Note: * denotes primary stress.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 364 / 47 = 7.7446$

$\beta = 0.875 * r_o / R_m = 0.875 * 109.54 / 364 = 0.2633$

Pressure stress intensity factor, I = 1.541 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = I*P*R_i / T =200.679 MPa

Local longitudinal pressure stress = I*P*R_i / (2*T) =100.339 MPa

Maximum combined stress (P_L+P_b+Q) = 214.9 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 204.98 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	$N_\phi / (P / R_m)$	1.1011	0	0	0	0	0.462	0.462	0.462	0.462
4C*	$N_\phi / (P / R_m)$	1.2994	0.545	0.545	0.545	0.545	0	0	0	0
1C	M_ϕ / P	0.1044	0	0	0	0	2.027	-2.027	2.027	-2.027
2C-1	M_ϕ / P	0.0753	1.462	-1.462	1.462	-1.462	0	0	0	0
3A*	$N_\phi / [M_c / (R_m^2 * \beta)]$	0.2717	0	0	0	0	-1.131	-1.131	1.131	1.131
1A	$M_\phi / [M_c / (R_m * \beta)]$	0.095	0	0	0	0	-18.361	18.361	18.361	-18.361
3B*	$N_\phi / [M_L / (R_m^2 * \beta)]$	0.9028	-3.758	-3.758	3.758	3.758	0	0	0	0
1B-1	$M_\phi / [M_L / (R_m * \beta)]$	0.0436	-8.425	8.425	8.425	-8.425	0	0	0	0
Pressure stress*			200.679	200.679	200.679	200.679	130.228	130.228	130.228	130.228
Total circumferential stress			190.502	204.43	214.868	195.094	113.226	145.893	152.209	111.433
Primary membrane circumferential stress*			197.466	197.466	204.981	204.981	129.559	129.559	131.821	131.821
3C*	$N_x / (P / R_m)$	1.1011	0.462	0.462	0.462	0.462	0	0	0	0
4C*	$N_x / (P / R_m)$	1.2994	0	0	0	0	0.545	0.545	0.545	0.545
1C-1	M_x / P	0.1043	2.027	-2.027	2.027	-2.027	0	0	0	0
2C	M_x / P	0.075	0	0	0	0	1.455	-1.455	1.455	-1.455
4A*	$N_x / [M_c / (R_m^2 * \beta)]$	0.469	0	0	0	0	-1.951	-1.951	1.951	1.951
2A	$M_x / [M_c / (R_m * \beta)]$	0.0554	0	0	0	0	-10.708	10.708	10.708	-10.708
4B*	$N_x / [M_L / (R_m^2 * \beta)]$	0.2719	-1.131	-1.131	1.131	1.131	0	0	0	0
2B-1	$M_x / [M_L / (R_m * \beta)]$	0.0707	-13.665	13.665	13.665	-13.665	0	0	0	0
Pressure stress*			65.114	65.114	65.114	65.114	100.339	100.339	100.339	100.339
Total longitudinal stress			52.807	76.084	82.399	51.014	89.68	108.186	114.998	90.673
Primary membrane longitudinal stress*			64.445	64.445	66.707	66.707	98.933	98.933	102.835	102.835
Shear from M_t			2.317	2.317	2.317	2.317	2.317	2.317	2.317	2.317
Circ shear from V_c			0.365	0.365	-0.365	-0.365	0	0	0	0
Long shear from V_L			0	0	0	0	-0.365	-0.365	0.365	0.365
Total Shear stress			2.682	2.682	1.951	1.951	1.951	1.951	2.682	2.682
Combined stress (P_L+P_b+Q)			190.557	204.485	214.896	195.122	113.384	145.996	152.402	111.771

Note: * denotes primary stress.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
= 8,116.25 / 1000*99.84 / (2*8.11) - -7,158 / (π*(109.54^2 - 99.84^2)) + 9,644,934.2*109.54 / 3.5039E+07
= 81.214 MPa

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 118 MPa)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
= (5,883^2 + 5,883^2)$^{0.5}$ / (π*99.84*9.7)
= 2.735 MPa

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
= 8,220 / (2*π*99.84^2*9.7)

= 13.531 MPa

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 2.735 + 13.531
= 16.265 MPa

UG-45: The total combined shear stress (16.265 MPa) ≤ allowable (0.7*S_n = 0.7*118 = 82.6 MPa)

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (cm^2) For P = 9,048.06 kPa @ 25 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
47.1436	47.1445	2.1135	4.7722	--	37.5	2.7587	7.78	11.11

UG-41 Weld Failure Path Analysis Summary (N) 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
624,749	621,427	888,894	155,070	1,975,957	696,360	1,427,374

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.7	weld size is adequate
Pad to shell fillet (Leg_{42})	9.5	9.8	weld size is adequate
Nozzle to pad groove (Upper)	8.89	25	weld size is adequate

Calculations for internal pressure 9,048.06 kPa @ 25 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(193.68, 96.84 + (12.7 - 0) + (25 - 0))
= 193.68 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(25 - 0), 2.5*(12.7 - 0) + 25)
= 56.75 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 9,048.0631*96.84 / (118,000*1 - 0.6*9,048.0631)
= 7.78 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 9,048.0631*350 / (138,000*1 - 0.6*9,048.0631)

= 23.89 mm

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

t_r = $P*R / (S*E - 0.6*P)$
= $9{,}048.0631*350 / (138{,}000*1 - 0.6*9{,}048.0631)$
= 23.89 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $(193.68*23.89*1 + 2*12.7*23.89*1*(1 - 0.8551)) / 100$
= 47.1436 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 2.1135 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(193.68*(1*25 - 1*23.89) - 2*12.7*(1*25 - 1*23.89)*(1 - 0.8551)) / 100$
= 2.1135 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(2*(25 + 12.7)*(1*25 - 1*23.89) - 2*12.7*(1*25 - 1*23.89)*(1 - 0.8551)) / 100$
= 0.7981 cm^2

A_2 = smaller of the following= 4.7722 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $(5*(12.7 - 7.78)*0.8551*25) / 100$
= 5.2561 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $(2*(12.7 - 7.78)*(2.5*12.7 + 25)*0.8551) / 100$
= 4.7722 cm^2

A_{41} = Leg^2*f_{r3}
= $(11^2*0.8551) / 100$
= 1.0348 cm^2

A_{42} = $Leg^2 * f_{r4}$
= $(13.13^2*1) / 100$
= 1.7239 cm^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $((369.08 - 193.68 - 2*12.7)*25*1) / 100$
= 37.5 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 2.1135 + 4.7722 + 1.0348 + 1.7239 + 37.5
= 47.1445 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 12.7 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 19 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 9.5 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*14 = 9.8 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 9,048.0631*96.84 / (118,000*1 - 0.6*9,048.0631) + 0
= 7.78 mm

$t_{a\ UG\text{-}22}$ = 6.1 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[7.78 , 6.1]
= 7.78 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 9,048.0631*350 / (138,000*1 - 0.6*9,048.0631) + 0
= 23.89 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[23.89 , 1.5]
= 23.89 mm

t_b = min[t_{b3} , t_{b1}]
= min[7.16 , 23.89]
= 7.16 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[7.78 , 7.16]
= 7.78 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*219.08*11*57.82 = 218,868.63 N

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*369.08*14*67.62 = 548,829.9 N

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*206.38*12.7*82.6 = 340,064.1 N

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*219.08*25*102.12 = 878,544.1 N

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*219.08*25*102.12 = 878,544.1 N

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 t_n f_{r1}(E_1 t - F t_r)) S_v$
= (4,714.3649 - 211.3544 + 2*12.7*0.8551*(1*25 - 1*23.89))*138
= 624,749.46 N

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42}) S_v$
= (477.2249 + 3,750 + 103.4837 + 172.3868)*138
= 621,427.23 N

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2 t_n t f_{r1}) S_v$
= (477.2249 + 0 + 103.4837 + 0 + 2*12.7*25*0.8551)*138
= 155,070.21 N

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$

= (477.2249 + 0 + 3,750 + 103.4837 + 172.3868 + 0 + 2*12.7*25*0.8551)*138

= 696,359.65 N

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 621,427.23 N
Path 1-1 through (2) & (3) = 548,829.9 + 340,064.1 = 888,894 N
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 155,070.21 N
Path 2-2 through (1), (4), (6) = 218,868.63 + 878,544.1 + 878,544.1 = 1,975,956.83 N
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

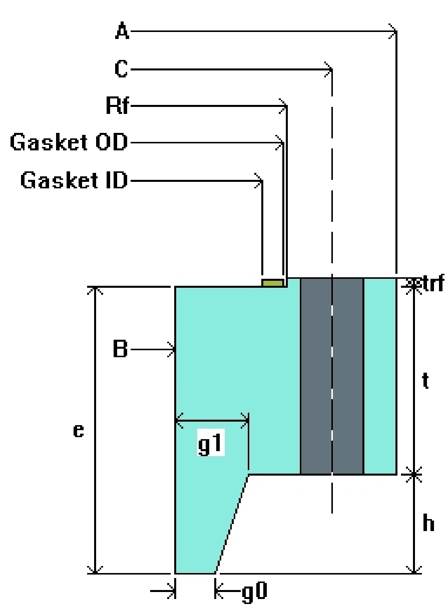
Load for path 3-3 lesser of W or $W_{3\text{-}3}$ = 624,749.46 N
Path 3-3 through (2), (4) = 548,829.9 + 878,544.1 = 1,427,374 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Shell Side Flange (front)

ASME VIII-1, 2013 Edition Metric, Appendix 2 Flange Calculations

Flange is attached to:	Shell #1 (Left)	
Flange type:	Weld neck integral	
Flange material specification:	SA-105 (II-D Metric p. 18, ln. 32)	
Bolt material specification:	SA-193 B7 Bolt <= 64 (II-D Metric p. 352, ln. 31)	
Bolt Description:	1.5 in Series 8 Thread	
Internal design pressure, P:	7,700.01 kPa @ 85 °C	
Required flange thickness, t_r:	105.09 mm	
Maximum allowable working pressure, MAWP:	7,961.61 kPa @ 85 °C	(bolting limits)
Maximum allowable pressure, MAP:	7,961.61 kPa @ 25 °C	(bolting limits)
Corrosion allowance:	Bore = 3 mm	Flange = 0 mm
Bolt corrosion (root), C_{bolt}:	0 mm	
Design MDMT:	-29 °C	No impact test performed
Rated MDMT:	-29 °C	Flange material is normalized Material is produced to fine grain practice PWHT is not performed
Estimated weight:	New = 364.6 kg	corroded = 355.48 kg

Flange dimensions, new



flange OD	A	= 970 mm
bolt circle	C	= 892 mm
raised face ID	Rf	= 836 mm
gasket OD		= 833 mm
gasket ID		= 807 mm
flange ID	B	= 700 mm
facing height	t_{rf}	= 5 mm
thickness	t	= 115 mm
bolting		= 32- 1.5 in dia
hub thickness	g_1	= 45 mm
hub thickness	g_0	= 25 mm
hub length	h	= 60 mm
length	e	= 175 mm
gasket factor	m	= 3
seating stress	y	= 68.948 MPa

Gasket thickness T = 4.45 mm

Note: this flange is calculated as an integral type.

Determination of Flange MDMT

Flange is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm
Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C

The rated flange MDMT is -29 °C

Flange calculations for Internal Pressure + Weight Only

Gasket details from facing sketch Confined gasket 1(a), Column II

Gasket width N = 13 mm

b_0 = N/2 = 6.5 mm

Effective gasket seating width, b = 2.5*$b_0^{1/2}$ = 6.37 mm

G = OD of contact face - 2*b = 833 - 2*6.37 = 820.25 mm

h_G = (C - G)/2 = (892 - 820.25)/2 = 35.87 mm

h_D = R + g_1/2 = 51 + 42/2 = 72 mm

h_T = (R + g_1 + h_G)/2 = (51 + 42 + 35.87)/2 = 64.44 mm

H_p = 2*b*3.14*G*m*P
= 2*6.37*3.14*820.25*3*7.7
= 758,324.92 N

H = 0.785*G^2*P
= 0.785*820.25^2*7.7
= 4,066,850.57 N

H_D = 0.785*B^2*P
= 0.785*706^2*7.7
= 3,012,797.67 N

H_T = H - H_D
= 4,066,850.57 - 3,012,797.67
= 1,054,052.9 N

W_{m1} = H + H_p
= 4,066,850.57 + 758,324.92
= 4,825,175.49 N

W_{m2} = 3.14*b*G*y
= 3.14*6.37*820.25*68.9476
= 1,131,700.61 N

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 280.5334 cm^2

A_{m1} = W_{m1}/S_b = 4,825,175.49/(100*172) = 280.5334 cm^2

A_{m2} = W_{m2}/S_a = 1,131,700.61/(100*172) = 65.7965 cm^2

Total area for 32- 1.5 in dia bolts, corroded, A_b = 290.0639 cm^2

W = (A_m + A_b)*S_a/2

= (28,053.34 + 29,006.39)*172/2
= 4,907,137.87 N

$M_D = H_D*h_D$ = 3,012,797.67*0.072 = 216,921.8 N-m
$M_T = H_T*h_T$ = 1,054,052.9*0.0644 = 67,919.5 N-m

$H_G = W_{m1} - H$ = 4,825,175.49 - 4,066,850.57 = 758,324.92 N

$M_G = H_G*h_G$ = 758,324.92*0.0359 = 27,203.3 N-m

$M_o = M_D + M_T + M_G$ = 216,921.8 + 67,919.5 + 27,203.3 = 312,044.5 N-m

$M_g = W*h_G$ = 4,907,137.87*0.0359 = 176,033 N-m

The bolts are adequately spaced so the TEMA RCB-11.23 load concentration factor does not apply.

Hub and Flange Factors

g_0 = min(g_0, t_n) = min(22, 22) = 22

h_0 = (B*g_0)$^{1/2}$ = (706*22)$^{1/2}$ = 124.63 mm

From FIG. 2-7.1, where K = A/B = 970/706 = 1.3739

T = 1.7655	Z = 3.253	Y = 6.273	U = 6.8934
h/h_0 = 0.4814	g_1/g_0 = 1.9091		
F = 0.8323	V = 0.2433	e = F/h_0 = 0.0668	

d = (U/V)*h_0*g_0^2= (6.8934/0.2433)*12.4627*2.2^2
= 1,708.7243 cm^3

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

f = 1.1682

L = (t*e + 1)/T + t^3/d
= (11.5*0.0668 + 1)/1.7655 + 11.5^3/1,708.7243
= 1.8915

S_H = f*M_o/(L*g_1^2*B)
= 1e3*1.1682*312,044.5/(1.8915*42^2*706)
= 154.755 MPa

S_R = (1.33*t*e + 1)*M_o/(L*t^2*B)
= (1.33*115*0.0067 + 1)*1e3*312,044.5/(1.8915*115^2*706)
= 35.718 MPa

S_T = Y*M_o/(t^2*B) - Z*S_R
= 1e3*6.273*312,044.5/(115^2*706) - 3.253*35.718
= 93.459 MPa

Allowable stress S_{fo} = 138 MPa
Allowable stress S_{no} = 138 MPa

S_T does not exceed S_{fo}
S_H does not exceed Min[1.5*S_{fo}, 2.5*S_{no}] = 207 MPa
S_R does not exceed S_{fo}
0.5(S_H + S_R) = 95.236 MPa does not exceed S_{fo}
0.5(S_H + S_T) = 124.107 MPa does not exceed S_{fo}

Flange rigidity at operating per VIII-1 Appendix 2-14

J = 52.14*V*M_o/(L*E*g_0^2*K_I*h_0)
= 1e3*52.14*0.2433*312,044.5/(1.8915*197.8E+03*22^2*0.3*124.63)
= 0.5848

The flange rigidity index J does not exceed 1; satisfactory.

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

S_H = f*M_g/(L*g_1^2*B)
= 1e3*1.1682*176,033/(1.8915*42^2*706)

= 87.301 MPa

$S_R = (1.33*t*e + 1)*M_g/(L*t^2*B)$
$= (1.33*115*0.0067 + 1)*1e3*176{,}033/(1.8915*115^2*706)$
= 20.149 MPa

$S_T = Y*M_g/(t^2*B) - Z*S_R$
$= 6.273*1e3*176{,}033/(115^2*706) - 3.253*20.149$
= 52.723 MPa

Allowable stress S_{fa} = 138 MPa
Allowable stress S_{na} = 138 MPa

S_T does not exceed S_{fa}
S_H does not exceed Min[$1.5*S_{fa}$, $2.5*S_{na}$] = 207 MPa
S_R does not exceed S_{fa}
$0.5(S_H + S_R)$ = 53.725 MPa does not exceed S_{fa}
$0.5(S_H + S_T)$ = 70.012 MPa does not exceed S_{fa}

Flange rigidity at gasket seating per VIII-1 Appendix 2-14

$J = 52.14*V*M_o/(L*E*g_0^2*K_l*h_0)$
$= 1e3*52.14*0.2433*176{,}033/(1.8915*201.23E{+}03*22^2*0.3*124.63)$
= 0.3243

The flange rigidity index J does not exceed 1; satisfactory.

Shell Side Flange (front) - Flange hub

ASME Section VIII Division 1, 2013 Edition Metric

Component:	Flange hub
Material specification:	SA-105 (II-D Metric p. 18, ln. 32)

Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.55 kPa (SG = 1, H_s = 975 mm, Horizontal test head)

Corrosion allowance Inner C = 3 mm Outer C = 0 mm

Design MDMT = -29 °C	No impact test performed
Rated MDMT = -29 °C	Material is normalized
	Material is produced to Fine Grain Practice
	PWHT is not performed

Radiography:	Longitudinal joint -	Seamless No RT
	Left circumferential joint -	N/A
	Right circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 25.8 kg	corr = 22.9 kg
Capacity	New = 23.09 liters	corr = 23.49 liters

ID = 700 mm
Length L_c = 60 mm
t = 25 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*22 / (353 + 0.60*22) - 0
= 8,290.65 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*25 / (350 + 0.60*25)
= 9,452.05 kPa

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 22)
= 0.007333
B = 119.47 MPa
S = 138 / 1.00 = 138 MPa
S_{cHC} = min(B, S) = 119.47 MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 25)
= 0.008333
B = 119.63 MPa
S = 138 / 1.00 = 138 MPa
S_{cHN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 25)
= 0.008333
B = 119.63 MPa
S = 138 / 1.00 = 138 MPa
S_{cCN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCC}	=	min(B, S) = 119.47 MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

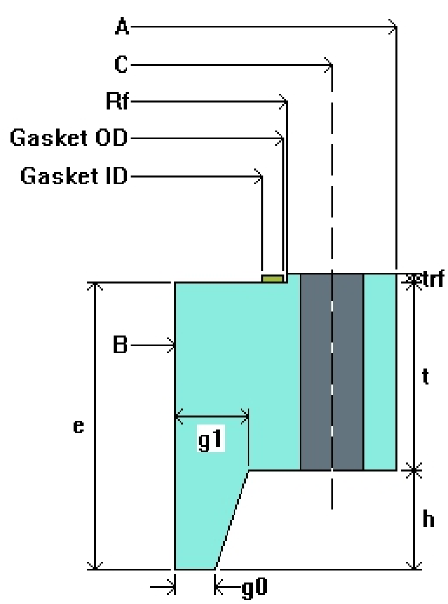
A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cVC}	=	min(B, S) = 119.47 MPa

Shell Side Flange (rear)

ASME VIII-1, 2013 Edition Metric, Appendix 2 Flange Calculations

Flange is attached to:	Shell #1 (Right)	
Flange type:	Weld neck integral	
Flange material specification:	SA-105 (II-D Metric p. 18, ln. 32)	
Bolt material specification:	SA-193 B7 Bolt <= 64 (II-D Metric p. 352, ln. 31)	
Bolt Description:	1.5 in Series 8 Thread	
Internal design pressure, P:	7,700.01 kPa @ 85 °C	
Required flange thickness, t_r:	105.09 mm	
Maximum allowable working pressure, MAWP:	7,961.61 kPa @ 85 °C	(bolting limits)
Maximum allowable pressure, MAP:	7,961.61 kPa @ 25 °C	(bolting limits)
Corrosion allowance:	Bore = 3 mm	Flange = 0 mm
Bolt corrosion (root), C_{bolt}:	0 mm	
Design MDMT:	-29 °C	No impact test performed
Rated MDMT:	-29 °C	Flange material is normalized Material is produced to fine grain practice PWHT is not performed
Estimated weight:	New = 364.6 kg	corroded = 355.48 kg

Flange dimensions, new



flange OD	A	= 970 mm
bolt circle	C	= 892 mm
raised face ID	Rf	= 836 mm
gasket OD		= 833 mm
gasket ID		= 807 mm
flange ID	B	= 700 mm
facing height	t_{rf}	= 5 mm
thickness	t	= 115 mm
bolting		= 32- 1.5 in dia
hub thickness	g_1	= 45 mm
hub thickness	g_0	= 25 mm
hub length	h	= 60 mm
length	e	= 175 mm
gasket factor	m	= 3
seating stress	y	= 68.948 MPa
Gasket thickness	T	= 4.45 mm
gasket description	Flexitallic Spiral Wound CG 304 S.S.	

Note: this flange is calculated as an integral type.

Determination of Flange MDMT

Flange is impact test exempt per UG-20(f)

UCS-66 governing thickness = 25 mm
Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C

The rated flange MDMT is -29 °C

Flange calculations for Internal Pressure + Weight Only

Gasket details from facing sketch Confined gasket 1(a), Column II

Gasket width N = 13 mm

b_0 = N/2 = 6.5 mm

Effective gasket seating width, b = $2.5*b_0^{1/2}$ = 6.37 mm

G = OD of contact face - 2*b = 833 - 2*6.37 = 820.25 mm

h_G = (C - G)/2 = (892 - 820.25)/2 = 35.87 mm

h_D = R + g_1/2 = 51 + 42/2 = 72 mm

h_T = (R + g_1 + h_G)/2 = (51 + 42 + 35.87)/2 = 64.44 mm

H_p = 2*b*3.14*G*m*P
= 2*6.37*3.14*820.25*3*7.7
= 758,324.92 N

H = 0.785*G^2*P
= 0.785*820.25^2*7.7
= 4,066,850.57 N

H_D = 0.785*B^2*P
= 0.785*706^2*7.7
= 3,012,797.67 N

H_T = H - H_D
= 4,066,850.57 - 3,012,797.67
= 1,054,052.9 N

W_{m1} = H + H_p
= 4,066,850.57 + 758,324.92
= 4,825,175.49 N

W_{m2} = 3.14*b*G*y
= 3.14*6.37*820.25*68.9476
= 1,131,700.61 N

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 280.5334 cm^2

A_{m1} = W_{m1}/S_b = 4,825,175.49/(100*172) = 280.5334 cm^2

A_{m2} = W_{m2}/S_a = 1,131,700.61/(100*172) = 65.7965 cm^2

Total area for 32- 1.5 in dia bolts, corroded, A_b = 290.0639 cm^2

W = (A_m + A_b)*S_a/2
= (28,053.34 + 29,006.39)*172/2

= 4,907,137.87 N

$M_D = H_D*h_D$ = 3,012,797.67*0.072 = 216,921.8 N-m
$M_T = H_T*h_T$ = 1,054,052.9*0.0644 = 67,919.5 N-m

$H_G = W_{m1} - H$ = 4,825,175.49 - 4,066,850.57 = 758,324.92 N

$M_G = H_G*h_G$ = 758,324.92*0.0359 = 27,203.3 N-m

$M_o = M_D + M_T + M_G$ = 216,921.8 + 67,919.5 + 27,203.3 = 312,044.5 N-m

$M_g = W*h_G$ = 4,907,137.87*0.0359 = 176,033 N-m

The bolts are adequately spaced so the TEMA RCB-11.23 load concentration factor does not apply.

Hub and Flange Factors

g_0 = min(g_0, t_n) = min(22, 22) = 22

h_0 = (B*g_0)$^{1/2}$ = (706*22)$^{1/2}$ = 124.63 mm

From FIG. 2-7.1, where K = A/B = 970/706 = 1.3739

T = 1.7655	Z = 3.253	Y = 6.273	U = 6.8934
h/h_0 = 0.4814	g_1/g_0 = 1.9091		
F = 0.8323	V = 0.2433	e = F/h_0 = 0.0668	

d = (U/V)*h_0*g_0^2= (6.8934/0.2433)*12.4627*2.2^2
= 1,708.7243 cm^3

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

f = 1.1682

L = (t*e + 1)/T + t^3/d
= (11.5*0.0668 + 1)/1.7655 + 11.5^3/1,708.7243
= 1.8915

S_H = f*M_o/(L*g_1^2*B)
= 1e3*1.1682*312,044.5/(1.8915*42^2*706)
= 154.755 MPa

S_R = (1.33*t*e + 1)*M_o/(L*t^2*B)
= (1.33*115*0.0067 + 1)*1e3*312,044.5/(1.8915*115^2*706)
= 35.718 MPa

S_T = Y*M_o/(t^2*B) - Z*S_R
= 1e3*6.273*312,044.5/(115^2*706) - 3.253*35.718
= 93.459 MPa

Allowable stress S_{fo} = 138 MPa
Allowable stress S_{no} = 138 MPa

S_T does not exceed S_{fo}
S_H does not exceed Min[1.5*S_{fo}, 2.5*S_{no}] = 207 MPa
S_R does not exceed S_{fo}
0.5(S_H + S_R) = 95.236 MPa does not exceed S_{fo}
0.5(S_H + S_T) = 124.107 MPa does not exceed S_{fo}

Flange rigidity at operating per VIII-1 Appendix 2-14

J = 52.14*V*M_o/(L*E*g_0^2*K_I*h_0)
= 1e3*52.14*0.2433*312,044.5/(1.8915*197.8E+03*22^2*0.3*124.63)
= 0.5848

The flange rigidity index J does not exceed 1; satisfactory.

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

S_H = f*M_g/(L*g_1^2*B)
= 1e3*1.1682*176,033/(1.8915*42^2*706)

= 87.301 MPa

S_R = (1.33*t*e + 1)*M_g/(L*t^2*B)
= (1.33*115*0.0067 + 1)*1e3*176,033/(1.8915*115^2*706)
= 20.149 MPa

S_T = Y*M_g/(t^2*B) - Z*S_R
= 6.273*1e3*176,033/(115^2*706) - 3.253*20.149
= 52.723 MPa

Allowable stress S_{fa} = 138 MPa
Allowable stress S_{na} = 138 MPa

S_T does not exceed S_{fa}
S_H does not exceed Min[1.5*S_{fa}, 2.5*S_{na}] = 207 MPa
S_R does not exceed S_{fa}
0.5(S_H + S_R) = 53.725 MPa does not exceed S_{fa}
0.5(S_H + S_T) = 70.012 MPa does not exceed S_{fa}

Flange rigidity at gasket seating per VIII-1 Appendix 2-14

J = 52.14*V*M_o/(L*E*g_0^2*K_I*h_0)
= 1e3*52.14*0.2433*176,033/(1.8915*201.23E+03*22^2*0.3*124.63)
= 0.3243

The flange rigidity index J does not exceed 1; satisfactory.

Shell Side Flange (rear) - Flange hub

ASME Section VIII Division 1, 2013 Edition Metric

Component:	Flange hub
Material specification:	SA-105 (II-D Metric p. 18, ln. 32)

Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.55 kPa (SG = 1, H_s = 975 mm, Horizontal test head)

Corrosion allowance	Inner C = 3 mm	Outer C = 0 mm

Design MDMT = -29 °C	No impact test performed
Rated MDMT = -29 °C	Material is normalized
	Material is produced to Fine Grain Practice
	PWHT is not performed

Radiography:	Longitudinal joint -	Seamless No RT
	Left circumferential joint -	Full UW-11(a) Type 1
	Right circumferential joint -	N/A

Estimated weight	New = 25.8 kg	corr = 22.9 kg
Capacity	New = 23.09 liters	corr = 23.49 liters

ID	=	700 mm
Length L_c	=	60 mm
t	=	25 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*22 / (353 + 0.60*22) - 0
= 8,290.65 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*25 / (350 + 0.60*25)
= 9,452.05 kPa

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 22)
= 0.007333

B = 119.47 MPa

S = 138 / 1.00 = 138 MPa

S_{cHC} = min(B, S) = 119.47 MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 25)
= 0.008333

B = 119.63 MPa

S = 138 / 1.00 = 138 MPa

S_{cHN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 25)
= 0.008333

B = 119.63 MPa

S = 138 / 1.00 = 138 MPa

S_{cCN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCC}	=	min(B, S) = 119.47 MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

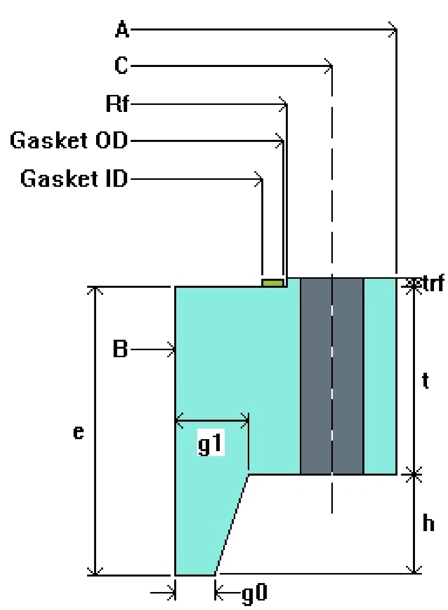
A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cVC}	=	min(B, S) = 119.47 MPa

Tube Side Flange (front)

ASME VIII-1, 2013 Edition Metric, Appendix 2 Flange Calculations

Flange is attached to:	Front Channel (Right)	
Flange type:	Weld neck integral	
Flange material specification:	SA-105 (II-D Metric p. 18, ln. 32)	
Bolt material specification:	SA-193 B7 Bolt <= 64 (II-D Metric p. 352, ln. 31)	
Bolt Description:	1.5 in Series 8 Thread	
Internal design pressure, P:	7,700.01 kPa @ 85 °C	
Required flange thickness, t_r:	105.09 mm	
Maximum allowable working pressure, MAWP:	7,961.61 kPa @ 85 °C	(bolting limits)
Maximum allowable pressure, MAP:	7,961.61 kPa @ 25 °C	(bolting limits)
Corrosion allowance:	Bore = 3 mm	Flange = 0 mm
Bolt corrosion (root), C_{bolt}:	0 mm	
Design MDMT:	-29 °C	No impact test performed
Rated MDMT:	-29 °C	Flange material is normalized Material is produced to fine grain practice PWHT is not performed
Estimated weight:	New = 365.46 kg	corroded = 356.3 kg

Flange dimensions, new



flange OD	A	= 970 mm
bolt circle	C	= 892 mm
raised face ID	Rf	= 836 mm
gasket OD		= 833 mm
gasket ID		= 807 mm
flange ID	B	= 700 mm
facing height	t_{rf}	= 5 mm
thickness	t	= 115 mm
bolting		= 32- 1.5 in dia
hub thickness	g_1	= 45 mm
hub thickness	g_0	= 25 mm
hub length	h	= 60 mm
length	e	= 177 mm
gasket factor	m	= 3
seating stress	y	= 68.948 MPa

Gasket thickness T = 4.45 mm

Note: this flange is calculated as an integral type.

Determination of Flange MDMT

UCS-66(b)(1)(b) has been applied.
Flange is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm
Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C

The rated flange MDMT is -29 °C

Flange calculations for Internal Pressure + Weight Only

Gasket details from facing sketch Confined gasket 1(a), Column II

Gasket width N = 13 mm

b_0 = N/2 = 6.5 mm

Effective gasket seating width, b = 2.5*$b_0^{1/2}$ = 6.37 mm

G = OD of contact face - 2*b = 833 - 2*6.37 = 820.25 mm

h_G = (C - G)/2 = (892 - 820.25)/2 = 35.87 mm

h_D = R + g_1/2 = 51 + 42/2 = 72 mm

h_T = (R + g_1 + h_G)/2 = (51 + 42 + 35.87)/2 = 64.44 mm

H_p = 2*b*3.14*G*m*P
= 2*6.37*3.14*820.25*3*7.7
= 758,324.92 N

H = 0.785*G^2*P
= 0.785*820.25^2*7.7
= 4,066,850.57 N

H_D = 0.785*B^2*P
= 0.785*706^2*7.7
= 3,012,797.67 N

H_T = H - H_D
= 4,066,850.57 - 3,012,797.67
= 1,054,052.9 N

W_{m1} = H + H_p
= 4,066,850.57 + 758,324.92
= 4,825,175.49 N

W_{m2} = 3.14*b*G*y
= 3.14*6.37*820.25*68.9476
= 1,131,700.61 N

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 280.5334 cm^2

A_{m1} = W_{m1}/S_b = 4,825,175.49/(100*172) = 280.5334 cm^2

A_{m2} = W_{m2}/S_a = 1,131,700.61/(100*172) = 65.7965 cm^2

Total area for 32- 1.5 in dia bolts, corroded, A_b = 290.0639 cm^2

$W = (A_m + A_b)*S_a/2$
$= (28{,}053.34 + 29{,}006.39)*172/2$
$= 4{,}907{,}137.87$ N

$M_D = H_D*h_D = 3{,}012{,}797.67*0.072 = 216{,}921.8$ N-m
$M_T = H_T*h_T = 1{,}054{,}052.9*0.0644 = 67{,}919.5$ N-m

$H_G = W_{m1} - H = 4{,}825{,}175.49 - 4{,}066{,}850.57 = 758{,}324.92$ N

$M_G = H_G*h_G = 758{,}324.92*0.0359 = 27{,}203.3$ N-m

$M_o = M_D + M_T + M_G = 216{,}921.8 + 67{,}919.5 + 27{,}203.3 = 312{,}044.5$ N-m

$M_g = W*h_G = 4{,}907{,}137.87*0.0359 = 176{,}033$ N-m

The bolts are adequately spaced so the TEMA RCB-11.23 load concentration factor does not apply.

Hub and Flange Factors

g_0 = min(g_0, t_n) = min(22, 22) = 22

h_0 = (B*g_0)$^{1/2}$ = (706*22)$^{1/2}$ = 124.63 mm

From FIG. 2-7.1, where K = A/B = 970/706 = 1.3739

T = 1.7655	Z = 3.253	Y = 6.273	U = 6.8934
h/h_0 = 0.4814	g_1/g_0 = 1.9091		
F = 0.8323	V = 0.2433	e = F/h_0 = 0.0668	

d = (U/V)*h_0*g_0^2= (6.8934/0.2433)*12.4628*2.2^2
= 1,708.749 cm^3

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

f = 1.1682

L = (t*e + 1)/T + t^3/d
= (11.5*0.0668 + 1)/1.7655 + 11.5^3/1,708.749
= 1.8914

S_H = f*M_o/(L*g_1^2*B)
= 1e3*1.1682*312,044.5/(1.8914*42^2*706)
= 154.753 MPa

S_R = (1.33*t*e + 1)*M_o/(L*t^2*B)
= (1.33*115*0.0067 + 1)*1e3*312,044.5/(1.8914*115^2*706)
= 35.718 MPa

S_T = Y*M_o/(t^2*B) - Z*S_R
= 1e3*6.273*312,044.5/(115^2*706) - 3.253*35.718
= 93.458 MPa

Allowable stress S_{fo} = 138 MPa
Allowable stress S_{no} = 138 MPa

S_T does not exceed S_{fo}
S_H does not exceed Min[1.5*S_{fo}, 2.5*S_{no}] = 207 MPa
S_R does not exceed S_{fo}
0.5(S_H + S_R) = 95.236 MPa does not exceed S_{fo}
0.5(S_H + S_T) = 124.106 MPa does not exceed S_{fo}

Flange rigidity at operating per VIII-1 Appendix 2-14

J = 52.14*V*M_o/(L*E*g_0^2*K_I*h_0)
= 1e3*52.14*0.2433*312,044.5/(1.8914*197.8E+03*22^2*0.3*124.63)
= 0.5848

The flange rigidity index J does not exceed 1; satisfactory.

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

S_H = f*M_g/(L*g_1^2*B)
= 1e3*1.1682*176,033/(1.8914*42^2*706)

= 87.301 MPa

S_R = (1.33*t*e + 1)*M_g/(L*t^2*B)
= (1.33*115*0.0067 + 1)*1e3*176,033/(1.8914*115^2*706)
= 20.149 MPa

S_T = Y*M_g/(t^2*B) - Z*S_R
= 6.273*1e3*176,033/(115^2*706) - 3.253*20.149
= 52.722 MPa

Allowable stress S_{fa} = 138 MPa
Allowable stress S_{na} = 138 MPa

S_T does not exceed S_{fa}
S_H does not exceed Min[1.5*S_{fa}, 2.5*S_{na}] = 207 MPa
S_R does not exceed S_{fa}
0.5(S_H + S_R) = 53.725 MPa does not exceed S_{fa}
0.5(S_H + S_T) = 70.011 MPa does not exceed S_{fa}

Flange rigidity at gasket seating per VIII-1 Appendix 2-14

J = 52.14*V*M_o/(L*E*g_0^2*K_I*h_0)
= 1e3*52.14*0.2433*176,033/(1.8914*201.23E+03*22^2*0.3*124.63)
= 0.3243

The flange rigidity index J does not exceed 1; satisfactory.

Tube Side Flange (front) - Flange hub

ASME Section VIII Division 1, 2013 Edition Metric

Component:	Flange hub
Material specification:	SA-105 (II-D Metric p. 18, ln. 32)

Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.8 kPa (SG = 1, H_s = 1,000 mm, Horizontal test head)

Corrosion allowance Inner C = 3 mm Outer C = 0 mm

Design MDMT = -29 °C	No impact test performed
Rated MDMT = -29 °C	Material is normalized
	Material is produced to Fine Grain Practice
	PWHT is not performed

Radiography:	Longitudinal joint -	Seamless No RT
	Left circumferential joint -	Full UW-11(a) Type 1
	Right circumferential joint -	N/A

Estimated weight	New = 25.8 kg	corr = 22.9 kg
Capacity	New = 23.09 liters	corr = 23.49 liters

ID	=	700 mm
Length L_c	=	60 mm
t	=	25 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*22 / (353 + 0.60*22) - 0
= 8,290.65 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*25 / (350 + 0.60*25)
= 9,452.05 kPa

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

A	=	0.125 / (R_o / t)
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cHC}	=	min(B, S) = 119.47 MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

A	=	0.125 / (R_o / t)
	=	0.125 / (375 / 25)
	=	0.008333
B	=	119.63 MPa
S	=	138 / 1.00 = 138 MPa
S_{cHN}	=	min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

A	=	0.125 / (R_o / t)
	=	0.125 / (375 / 25)
	=	0.008333
B	=	119.63 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCN}	=	min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCC}	=	min(B, S) = 119.47 MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

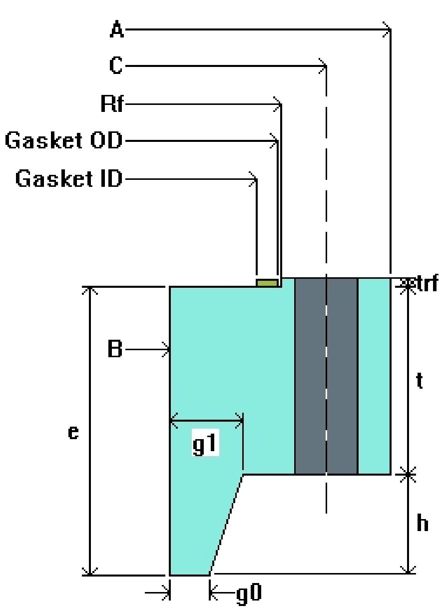
A	=	$0.125 / (R_o / t)$
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cVC}	=	min(B, S) = 119.47 MPa

Tube Side Flange (rear)

ASME VIII-1, 2013 Edition Metric, Appendix 2 Flange Calculations

Flange is attached to:	Rear Channel (Left)	
Flange type:	Weld neck integral	
Flange material specification:	SA-105 (II-D Metric p. 18, ln. 32)	
Bolt material specification:	SA-193 B7 Bolt <= 64 (II-D Metric p. 352, ln. 31)	
Bolt Description:	1.5 in Series 8 Thread	
Internal design pressure, P:	7,700.01 kPa @ 85 °C	
Required flange thickness, t_r:	105.09 mm	
Maximum allowable working pressure, MAWP:	7,961.61 kPa @ 85 °C	(bolting limits)
Maximum allowable pressure, MAP:	7,961.61 kPa @ 25 °C	(bolting limits)
Corrosion allowance:	Bore = 3 mm	Flange = 0 mm
Bolt corrosion (root), C_{bolt}:	0 mm	
Design MDMT:	-29 °C	No impact test performed
Rated MDMT:	-29 °C	Flange material is normalized Material is produced to fine grain practice PWHT is not performed
Estimated weight:	New = 365.46 kg	corroded = 356.3 kg

Flange dimensions, new



flange OD	A	= 970 mm
bolt circle	C	= 892 mm
raised face ID	Rf	= 836 mm
gasket OD		= 833 mm
gasket ID		= 807 mm
flange ID	B	= 700 mm
facing height	t_{rf}	= 5 mm
thickness	t	= 115 mm
bolting		= 32- 1.5 in dia
hub thickness	g_1	= 45 mm
hub thickness	g_0	= 25 mm
hub length	h	= 60 mm
length	e	= 177 mm
gasket factor	m	= 3
seating stress	y	= 68.948 MPa
Gasket thickness	T	= 4.45 mm
gasket description	Flexitallic Spiral Wound CG 304 S.S.	

Note: this flange is calculated as an integral type.

Determination of Flange MDMT

UCS-66(b)(1)(b) has been applied.

Flange is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm
Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C

The rated flange MDMT is -29 °C

Flange calculations for Internal Pressure + Weight Only

Gasket details from facing sketch Confined gasket 1(a), Column II

Gasket width N = 13 mm

b_0 = N/2 = 6.5 mm

Effective gasket seating width, b = 2.5*$b_0^{1/2}$ = 6.37 mm

G = OD of contact face - 2*b = 833 - 2*6.37 = 820.25 mm

h_G = (C - G)/2 = (892 - 820.25)/2 = 35.87 mm

h_D = R + g_1/2 = 51 + 42/2 = 72 mm

h_T = (R + g_1 + h_G)/2 = (51 + 42 + 35.87)/2 = 64.44 mm

H_p = 2*b*3.14*G*m*P
= 2*6.37*3.14*820.25*3*7.7
= 758,324.92 N

H = 0.785*G^2*P
= 0.785*820.25^2*7.7
= 4,066,850.57 N

H_D = 0.785*B^2*P
= 0.785*706^2*7.7
= 3,012,797.67 N

H_T = H - H_D
= 4,066,850.57 - 3,012,797.67
= 1,054,052.9 N

W_{m1} = H + H_p
= 4,066,850.57 + 758,324.92
= 4,825,175.49 N

W_{m2} = 3.14*b*G*y
= 3.14*6.37*820.25*68.9476
= 1,131,700.61 N

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 280.5334 cm^2

A_{m1} = W_{m1}/S_b = 4,825,175.49/(100*172) = 280.5334 cm^2

A_{m2} = W_{m2}/S_a = 1,131,700.61/(100*172) = 65.7965 cm^2

Total area for 32- 1.5 in dia bolts, corroded, A_b = 290.0639 cm^2

W = (A_m + A_b)*S_a/2

$= (28,053.34 + 29,006.39)*172/2$
$= 4,907,137.87$ N

$M_D = H_D*h_D = 3,012,797.67*0.072 = 216,921.8$ N-m
$M_T = H_T*h_T = 1,054,052.9*0.0644 = 67,919.5$ N-m

$H_G = W_{m1} - H = 4,825,175.49 - 4,066,850.57 = 758,324.92$ N

$M_G = H_G*h_G = 758,324.92*0.0359 = 27,203.3$ N-m

$M_o = M_D + M_T + M_G = 216,921.8 + 67,919.5 + 27,203.3 = 312,044.5$ N-m

$M_g = W*h_G = 4,907,137.87*0.0359 = 176,033$ N-m

The bolts are adequately spaced so the TEMA RCB-11.23 load concentration factor does not apply.

Hub and Flange Factors

g_0 = min(g_0, t_n) = min(22, 22) = 22

$h_0 = (B*g_0)^{1/2} = (706*22)^{1/2}$ = 124.63 mm

From FIG. 2-7.1, where K = A/B = 970/706 = 1.3739

T = 1.7655	Z = 3.253	Y = 6.273	U = 6.8934
h/h_0 = 0.4814	g_1/g_0 = 1.9091		
F = 0.8323	V = 0.2433	e = F/h_0 = 0.0668	

$d = (U/V)*h_0*g_0^2 = (6.8934/0.2433)*12.4628*2.2^2$
= 1,708.749 cm^3

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

f = 1.1682

$L = (t*e + 1)/T + t^3/d$
= $(11.5*0.0668 + 1)/1.7655 + 11.5^3/1,708.749$
= 1.8914

$S_H = f*M_o/(L*g_1^2*B)$
= $1e3*1.1682*312,044.5/(1.8914*42^2*706)$
= 154.753 MPa

$S_R = (1.33*t*e + 1)*M_o/(L*t^2*B)$
= $(1.33*115*0.0067 + 1)*1e3*312,044.5/(1.8914*115^2*706)$
= 35.718 MPa

$S_T = Y*M_o/(t^2*B) - Z*S_R$
= $1e3*6.273*312,044.5/(115^2*706) - 3.253*35.718$
= 93.458 MPa

Allowable stress S_{fo} = 138 MPa
Allowable stress S_{no} = 138 MPa

S_T does not exceed S_{fo}
S_H does not exceed Min[$1.5*S_{fo}$, $2.5*S_{no}$] = 207 MPa
S_R does not exceed S_{fo}
$0.5(S_H + S_R)$ = 95.236 MPa does not exceed S_{fo}
$0.5(S_H + S_T)$ = 124.106 MPa does not exceed S_{fo}

Flange rigidity at operating per VIII-1 Appendix 2-14

$J = 52.14*V*M_o/(L*E*g_0^2*K_I*h_0)$
= $1e3*52.14*0.2433*312,044.5/(1.8914*197.8E+03*22^2*0.3*124.63)$
= 0.5848

The flange rigidity index J does not exceed 1; satisfactory.

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

$S_H = f*M_g/(L*g_1^2*B)$
= $1e3*1.1682*176,033/(1.8914*42^2*706)$

= 87.301 MPa

S_R = (1.33*t*e + 1)*M_g/(L*t^2*B)
= (1.33*115*0.0067 + 1)*1e3*176,033/(1.8914*115^2*706)
= 20.149 MPa

S_T = Y*M_g/(t^2*B) - Z*S_R
= 6.273*1e3*176,033/(115^2*706) - 3.253*20.149
= 52.722 MPa

Allowable stress S_{fa} = 138 MPa
Allowable stress S_{na} = 138 MPa

S_T does not exceed S_{fa}
S_H does not exceed Min[1.5*S_{fa}, 2.5*S_{na}] = 207 MPa
S_R does not exceed S_{fa}
0.5(S_H + S_R) = 53.725 MPa does not exceed S_{fa}
0.5(S_H + S_T) = 70.011 MPa does not exceed S_{fa}

Flange rigidity at gasket seating per VIII-1 Appendix 2-14

J = 52.14*V*M_o/(L*E*g_0^2*K_I*h_0)
= 1e3*52.14*0.2433*176,033/(1.8914*201.23E+03*22^2*0.3*124.63)
= 0.3243

The flange rigidity index J does not exceed 1; satisfactory.

Tube Side Flange (rear) - Flange hub

ASME Section VIII Division 1, 2013 Edition Metric

Component: Flange hub
Material specification: SA-105 (II-D Metric p. 18, ln. 32)
Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 25 mm

Internal design pressure: P = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.8 kPa (SG = 1, H_s = 1,000 mm, Horizontal test head)

Corrosion allowance Inner C = 3 mm Outer C = 0 mm

Design MDMT = -29 °C No impact test performed
Rated MDMT = -29 °C Material is normalized
Material is produced to Fine Grain Practice
PWHT is not performed

Radiography:	Longitudinal joint -	Seamless No RT
	Left circumferential joint -	N/A
	Right circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 25.8 kg	corr = 22.9 kg
Capacity	New = 23.09 liters	corr = 23.49 liters

ID	=	700 mm
Length L_c	=	60 mm
t	=	25 mm

Design thickness, (at 85 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 7,700.01*353 / (138,000*1.00 - 0.60*7,700.01) + 3
= 23.38 mm

Maximum allowable working pressure, (at 85 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*22 / (353 + 0.60*22) - 0
= 8,290.65 kPa

Maximum allowable pressure, (at 25 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*25 / (350 + 0.60*25)
= 9,452.05 kPa

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 22)
= 0.007333

B = 119.47 MPa

S = 138 / 1.00 = 138 MPa

S_{cHC} = min(B, S) = 119.47 MPa

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 25)
= 0.008333

B = 119.63 MPa

S = 138 / 1.00 = 138 MPa

S_{cHN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

A = 0.125 / (R_o / t)
= 0.125 / (375 / 25)
= 0.008333

B = 119.63 MPa

S = 138 / 1.00 = 138 MPa

S_{cCN} = min(B, S) = 119.63 MPa

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

A	=	0.125 / (R_o / t)
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCC}	=	min(B, S) = 119.47 MPa

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

A	=	0.125 / (R_o / t)
	=	0.125 / (375 / 22)
	=	0.007333
B	=	119.47 MPa
S	=	138 / 1.00 = 138 MPa
S_{cVC}	=	min(B, S) = 119.47 MPa

Saddle

Saddle material:			A36
Saddle construction is:			Web at edge of rib
Saddle allowable stress:	S_s =	165.474	MPa
Saddle yield stress:	S_y =	248.211	MPa
Saddle distance to datum:		1,550	mm
Tangent to tangent length:	L =	13,653.29	mm
Saddle separation:	L_s =	10,500	mm
Vessel radius:	R =	375	mm
Tangent distance left:	A_l =	1,553.29	mm
Tangent distance right:	A_r =	1,600	mm
Tubesheet distance left:	A_{tsl} =	666.45	mm
Tubesheet distance right:	A_{tsr} =	703.56	mm
Saddle height:	H_s =	679.8	mm
Saddle contact angle:	θ =	120	°
Wear plate thickness:	t_p =	12	mm
Wear plate width:	W_p =	300	mm
Wear plate contact angle:	θ_w =	132	°
Web plate thickness:	t_s =	12	mm
Base plate length:	E =	685.8	mm
Base plate width:	F =	250	mm
Base plate thickness:	t_b =	19	mm
Number of stiffener ribs:	n =	2	
Largest stiffener rib spacing:	d_i =	648.4	mm
Stiffener rib thickness:	t_w =	12	mm
Saddle width:	b =	200	mm
Anchor bolt size & type:			1 inch series 8 threaded
Anchor bolt material:			SA-193 B8
Anchor bolt allowable shear:		129.621	MPa
Anchor bolt corrosion allowance:		0	mm
Anchor bolts per saddle:		4	
Base coefficient of friction:	μ =	0.45	

Weight on left saddle:	operating corr =	7,902.94 kg,	test new =	10,540.13 kg
Weight on right saddle:	operating corr =	7,924.26 kg,	test new =	10,580.5 kg
Weight of saddle pair	=	175.09 kg		

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.

Load	Vessel condition	Bending + pressure between saddles (MPa)				Bending + pressure at the saddle (MPa)			
		S_1 (+)	allow (+)	S_1 (-)	allow (-)	S_2 (+)	allow (+)	S_2 (-)	allow (-)
Weight	Operating	79.095	138	15.221	119.473	80.63	138	16.757	119.473
Weight	Test	90.53	235.8	18.012	119.473	92.358	235.8	19.841	119.473

Load	Vessel condition	Tangential shear (MPa)		Circumferential stress (MPa)		Stress over saddle (MPa)		Splitting (MPa)	
		S_3	allow	S_4 (horns)	allow (+/-)	S_5	allow	S_6	allow
Weight	Operating	8.582	110.4	-15.325	207	9.236	121	3.101	110.316
Weight	Test	10.112	188.64	-16.129	235.8	10.892	223.39	4.14	223.39

Load Case 1: Weight ,Operating

Longitudinal stress between saddles (Weight ,Operating, left saddle loading and geometry govern)

S_1 = +- 3*K_1*Q*(L / 12) / (π*R^2*t)
= 3*0.5269*77,501.37*(13,653.29 / 12) / (π*364^2*22)
= 15.221 MPa

S_p = P*R / (2*t)
= 7.96*353 / (2*22)
= 63.874 MPa

Maximum tensile stress S_{1t} = S_1 + S_p = 79.095 MPa
Maximum compressive stress (shut down) S_{1c} = S_1 = 15.221 MPa

Tensile stress is acceptable (<=1*S*E = 138 MPa)
Compressive stress is acceptable (<=1*S_c = 119.473 MPa)

Longitudinal stress at the right saddle (Weight ,Operating)

L_e = 2*(Left head depth) / 3 + L + 2*(Right head depth) / 3
= 2*199 / 3 + 13,653.29 + 2*199 / 3
= 13,918.62 mm

w = W_t / L_e = 155,211.81*10 / 13,918.62 = 111.51 N/cm

Bending moment at the right saddle:

M_q = w*(2*H*A_r / 3 + A_r^2 / 2 - (R^2 - H^2) / 4)
= 111.51 / 10000*(2*199*1,600 / 3 + $1,600^2$ / 2 - (375^2 - 199^2) / 4)
= 16,359.2 N-m

S_2 = +- M_q*K_1' / (π*R^2*t)
= 16,359.2*1e3*9.3799 / (π*364^2*22)
= 16.757 MPa

S_p = P*R / (2*t)
= 7.96*353 / (2*22)
= 63.874 MPa

Maximum tensile stress $S_{2t} = S_2 + S_p$ = 80.63 MPa
Maximum compressive stress (shut down) $S_{2c} = S_2$ = 16.757 MPa

Tensile stress is acceptable (<=1*S = 138 MPa)
Compressive stress is acceptable (<=1*S_c = 119.473 MPa)

Tangential shear stress in the shell (left saddle, Weight ,Operating)

Q_{shear} = Q - w*(a + 2*H / 3)
= 77,501.37 - 11.15*(1,553.29 + 2*199 / 3)
= 58,700.63 N

$S_3 = K_{2.2}*Q_{shear} / (R*t)$
= 1.1707*58,700.63 / (364*22)
= 8.582 MPa

Tangential shear stress is acceptable (<= 0.8*S = 110.4 MPa)

Circumferential stress at the right saddle horns (Weight ,Operating)

$S_4 = -Q / (4*t*(b+1.56*Sqr(R_o*t))) - 3*K_3*Q / (2*t^2)$
= -77,710.44 / (4*22*(200+1.56*Sqr(375*22))) - 3*0.0529*77,710.44 / (2*22^2)
= -15.325 MPa

Circumferential stress at saddle horns is acceptable (<=1.5*S_a = 207 MPa)
The wear plate was not considered in the calculation of S_4 because the wear plate width is not at least {B + 1.56*$(R_o t_c)^{0.5}$} =341.69 mm

Ring compression in shell over right saddle (Weight ,Operating)

$S_5 = K_5*Q / ((t + t_p)*(t_s + 1.56*Sqr(R_o*t_c)))$
= 0.7603*77,710.44 / ((22 + 12)*(12 + 1.56*Sqr(375*34)))
= 9.236 MPa

Ring compression in shell is acceptable (<= 0.5*S_y = 121 MPa)

Saddle splitting load (right, Weight ,Operating)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff}*t_s + t_p*W_p$
= 12.5*1.2 + 1.2*30
= 51 cm^2

$S_6 = K_8*Q / A_e$
= 0.2035*77,710.44 / 5,100
= 3.101 MPa

Stress in saddle is acceptable (<= (2 / 3)*S_s = 110.316 MPa)

Load Case 2: Weight ,Test

Longitudinal stress between saddles (Weight ,Test, left saddle loading and geometry govern)

$S_1 = +- 3*K_1*Q*(L / 12) / (\pi*R^2*t)$
= 3*0.5269*103,363.33*(13,653.29 / 12) / (π*362.5^2*25)

= 18.012 MPa

S_p = P*R / (2*t)
= 10.36*350 / (2*25)
= 72.518 MPa

Maximum tensile stress $S_{1t} = S_1 + S_p$ = 90.53 MPa
Maximum compressive stress (shut down) $S_{1c} = S_1$ = 18.012 MPa

Tensile stress is acceptable (<= 0.9*S_y = 235.8 MPa)
Compressive stress is acceptable (<=1*S_c = 119.473 MPa)

Longitudinal stress at the right saddle (Weight ,Test)

L_e = 2*(Left head depth) / 3 + L + 2*(Right head depth) / 3
= 2*199 / 3 + 13,653.29 + 2*199 / 3
= 13,918.62 mm

w = W_t / L_e = 207,122.56*10 / 13,918.62 = 148.81 N/cm

Bending moment at the right saddle:

M_q = w*(2*H*A_r / 3 + A_r^2 / 2 - (R^2 - H^2) / 4)
= 148.81 / 10000*(2*199*1,600 / 3 + $1{,}600^2$ / 2 - (375^2 - 199^2) / 4)
= 21,830.5 N-m

S_2 = +- M_q*K_1' / (π*R^2*t)
= 21,830.5*1e3*9.3799 / (π*362.5^2*25)
= 19.841 MPa

S_p = P*R / (2*t)
= 10.36*350 / (2*25)
= 72.518 MPa

Maximum tensile stress $S_{2t} = S_2 + S_p$ = 92.358 MPa
Maximum compressive stress (shut down) $S_{2c} = S_2$ = 19.841 MPa

Tensile stress is acceptable (<= 0.9*S_y = 235.8 MPa)
Compressive stress is acceptable (<=1*S_c = 119.473 MPa)

Tangential shear stress in the shell (left saddle, Weight ,Test)

Q_{shear} = Q - w*(a + 2*H / 3)
= 103,363.33 - 14.88*(1,553.29 + 2*199 / 3)
= 78,274.67 N

S_3 = $K_{2.2}$*Q_{shear} / (R*t)
= 1.1707*78,274.67 / (362.5*25)
= 10.112 MPa

Tangential shear stress is acceptable (<= 0.8*(0.9*S_y) = 188.64 MPa)

Circumferential stress at the right saddle horns (Weight ,Test)

S_4 = -Q / (4*t*(b+1.56*Sqr(R_o*t))) - 3*K_3*Q / (2*t^2)
= -103,759.23 / (4*25*(200+1.56*Sqr(375*25))) - 3*0.0529*103,759.23 / (2*25^2)
= -16.129 MPa

Circumferential stress at saddle horns is acceptable (<= 0.9*S_y = 235.8 MPa)
The wear plate was not considered in the calculation of S_4 because the wear plate width is not at least {B + 1.56*$(R_o t_c)^{0.5}$} =351.05 mm

Ring compression in shell over right saddle (Weight ,Test)

$S_5 = K_5*Q / ((t + t_p)*(t_s + 1.56*Sqr(R_o*t_c)))$
= 0.7603*103,759.23 / ((25 + 12)*(12 + 1.56*Sqr(375*37)))
= 10.892 MPa

Ring compression in shell is acceptable (<= 0.9*S_y = 223.39 MPa)

Saddle splitting load (right, Weight ,Test)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff}*t_s + t_p*W_p$
= 12.5*1.2 + 1.2*30
= 51 cm^2

$S_6 = K_8*Q / A_e$
= 0.2035*103,759.23 / 5,100
= 4.14 MPa

Stress in saddle is acceptable (<= 0.9*S_y = 223.39 MPa)

Shear stress in anchor bolting, one end slotted

Maximum seismic or wind base shear = 0 N

Thermal expansion base shear = W*μ = 78,568.95*0.45 = 35,356.03 N
Corroded root area for a 1 inch series 8 threaded bolt = 3.5548 cm^2 (4 per saddle)

Bolt shear stress = 35,356.03 / (355.4832*1*4) = 24.865 MPa

Anchor bolt stress is acceptable (<= 129.621 MPa)

Shear stress in anchor bolting, transverse

Maximum seismic or wind base shear = 0 N
Corroded root area for a 1 inch series 8 threaded bolt = 3.5548 cm^2 (4 per saddle)

Bolt shear stress = 0 / (355.4832*2*4) = 0 MPa

Anchor bolt stress is acceptable (<= 129.621 MPa)

Web plate buckling check (Escoe pg 251)

Allowable compressive stress S_c is the lesser of 165.474 or 79.228 MPa: (79.228)

$S_c = K_i*\pi^2*E / (12*(1 - 0.3^2)*(d_i / t_s)^2)$
= $1.28*\pi^2*199.95E+03 / (12*(1 - 0.3^2)*(648.4 / 12)^2)$
= 79.228 MPa

Allowable compressive load on the saddle

$b_e = d_i*t_s / (d_i*t_s + 2*t_w*(b - 25.4))*25.4$
= 648.4*12 / (648.4*12 + 2*12*(200 - 25.4))*25.4
= 16.51

$F_b = n*(A_s + 2*b_e*t_s)*S_c$
= 2*(2,256 + 2*16.51*12)*79.228
= 420,259.98 N

Saddle loading of 104,617.73 N is <= F_b; satisfactory.

Primary bending + axial stress in the saddle due to end loads (assumes one saddle slotted)
$\sigma_b = V*(H_s - x_o)*y / I + Q / A$
= 0*(679.8 - 310.12)*135.25 / (1e4*3,193.94) + 77,710.44 / 12,306.23
= 6.315 MPa

The primary bending + axial stress in the saddle <= 165.474 MPa; satisfactory.

Secondary bending + axial stress in the saddle due to end loads (includes thermal expansion, assumes one saddle slotted)
$\sigma_b = V*(H_s - x_o)*y / I + Q / A$
= 35,356.03*(679.8 - 310.12)*135.25 / (1e4*3,193.94) + 77,710.44 / 12,306.23
= 61.662 MPa

The secondary bending + axial stress in the saddle < $2*S_y$= 496.423 MPa; satisfactory.

Saddle base plate thickness check (Roark sixth edition, Table 26, case 7a)

where a = 648.4, b = 238 mm

$t_b = (\beta_1*q*b^2 / (1.5*S_a))^{0.5}$
= $(2.2719*0.61*238^2 / (1.5*165.474))^{0.5}$
= 17.79 mm

The base plate thickness of 19 mm is adequate.

Foundation bearing check

$S_f = Q_{max} / (F*E)$
= 104,617.73 / (250*685.8)
= 0.61 MPa

Concrete bearing stress ≤ 11.432 MPa ; satisfactory.

Baffle Summary Report

Baffle Name	Distance from Front Tubesheet (mm)	Cut Direction	Cut Distance from Center (mm)	Baffle Weight (kg)[1]
Baffle #1	460	Downwards	100.38	12.1
Baffle #2	670	Upwards	100.38	12.1
Baffle #3	880	Downwards	100.38	12.1
Baffle #4	1,090	Upwards	100.38	12.1
Baffle #5	1,300	Downwards	100.38	12.1
Baffle #6	1,510	Upwards	100.38	12.1
Baffle #7	1,720	Downwards	100.38	12.1
Baffle #8	1,930	Upwards	100.38	12.1
Baffle #9	2,140	Downwards	100.38	12.1
Baffle #10	2,350	Upwards	100.38	12.1
Baffle #11	2,560	Downwards	100.38	12.1
Baffle #12	2,770	Upwards	100.38	12.1
Baffle #13	2,980	Downwards	100.38	12.1
Baffle #14	3,190	Upwards	100.38	12.1
Baffle #15	3,400	Downwards	100.38	12.1
Baffle #16	3,610	Upwards	100.38	12.1
Baffle #17	3,820	Downwards	100.38	12.1
Baffle #18	4,030	Upwards	100.38	12.1
Baffle #19	4,240	Downwards	100.38	12.1
Baffle #20	4,450	Upwards	100.38	12.1
Baffle #21	4,660	Downwards	100.38	12.1
Baffle #22	4,870	Upwards	100.38	12.1
Baffle #23	5,080	Downwards	100.38	12.1
Baffle #24	5,290	Upwards	100.38	12.1
Baffle #25	5,500	Downwards	100.38	12.1
Baffle #26	5,710	Upwards	100.38	12.1
Baffle #27	5,920	Downwards	100.38	12.1
Baffle #28	6,130	Upwards	100.38	12.1
Baffle #29	6,340	Downwards	100.38	12.1
Baffle #30	6,550	Upwards	100.38	12.1
Baffle #31	6,760	Downwards	100.38	12.1
Baffle #32	6,970	Upwards	100.38	12.1
Baffle #33	7,180	Downwards	100.38	12.1
Baffle #34	7,390	Upwards	100.38	12.1
Baffle #35	7,600	Downwards	100.38	12.1
Baffle #36	7,810	Upwards	100.38	12.1
Baffle #37	8,020	Downwards	100.38	12.1

Baffle #38	8,230	Upwards	100.38	12.1
Baffle #39	8,440	Downwards	100.38	12.1
Baffle #40	8,650	Upwards	100.38	12.1
Baffle #41	8,860	Downwards	100.38	12.1
Baffle #42	9,070	Upwards	100.38	12.1
Baffle #43	9,280	Downwards	100.38	12.1
Baffle #44	9,490	Upwards	100.38	12.1
Baffle #45	9,700	Downwards	100.38	12.1
Baffle #46	9,910	Upwards	100.38	12.1
Baffle #47	10,120	Downwards	100.38	12.1
Baffle #48	10,330	Upwards	100.38	12.1
Baffle #49	10,540	Downwards	100.38	12.1
Baffle #50	10,750	Upwards	100.38	12.1
Baffle #51	10,960	Downwards	100.38	12.1
Baffle #52	11,170	Upwards	100.38	12.1

Baffle Material:	SA-36	
Baffle Type:	Single Segmental	
Baffle Orientation:	Horizontal	
Baffle Shell Clearance:	4.7 mm	(4.8 mm TEMA (Max))
Baffle Thickness:	10 mm	(4.8 mm TEMA)
Baffle Diameter:	695.3 mm	
Baffle Count:	52	
Maximum Tubesheet to Baffle Distance:	780 mm	
Maximum Baffle to Baffle Distance:	420 mm	
Distance between Tubesheet Shell Side Faces:	11,740 mm	
Baffle Group Weight:	628.9 kg	
Baffle Material Density (assumed):	7833.41 kg/m^3	

[1]*Note:* Baffle weight is approximated.

Data Inputs Summary

General Options				
Identifier	Heat Exchanger			
Codes	ASME VIII-1, 2013 Edition Metric		TEMA Ninth Edition (2007)	
Description	Fixed tubesheets	Class R	One pass shell	**SIZE 28-472.4409 TYPE BEM**
Shell material: SA-516 70	Expansion joint not used		Tubesheets of differing thickness method not used	Perform ASME tube design check
Tube supports\baffle plates present	Maximum tubesheet to tube support distance: 780 mm		Maximum tube support separation: 420 mm	Baffles support all tubes: No

Tube Options				
Tube material: SA-179 Smls. Tube	Length between outer tubesheet faces: L_t= 12,000 mm			
Tube dimensions, new, mm	d_o= 19.05	t_t= 2.77 (2.42 min)	Inner corrosion: 0	Outer corrosion: 0
Tube to tubesheet joint option	Table A-2 Type f, Welded, a <1.4*t, and expanded, enhanced with two or more grooves			

Channel and Shell Options						
Shell dimensions new, mm	Material: SA-516 70	D_i= 700	t_s= 25	Inner corrosion: 3	Outer corrosion: 0	MDMT: -29 °C
Front channel dimensions, new, mm	Type: bonnet	Ellipsoidal head		Inner corrosion: 3	Outer corrosion: 0	MDMT: -29 °C
	Cylinder	SA-516 70		D_i= 700	t_c= 25	L= 600
	Closure	SA-516 70		D_i= 700	t_{min}= 24	L_{SF}= 50
Rear channel dimensions, new, mm	Type: bonnet	Ellipsoidal head		Inner corrosion: 3	Outer corrosion: 0	MDMT: -29 °C
	Cylinder	SA-516 70		D_i= 700	t_c= 25	L= 600
	Closure	SA-516 70		D_i= 700	t_{min}= 24	L_{SF}= 50

Tubesheet Options							
Tube Layout	Shear does not govern		Tube hole count: 537	Tube pitch: 25.4 mm		Pattern: 90° (square)	
Tubesheet dimensions, mm (front and rear)	Material: SA-350 LF2 Cl 1	T = 130	OD = 970	Shell side corrosion = 3	Tube side corrosion = 3	MDMT = -29 °C	Tubesheet pass groove depth = 0
	Impact test is not performed	Normalized	Produced fine grain practice	PWHT not performed		Gasketed shell side	Gasketed tube side

Design Conditions Summary

Design Conditions				
Description		Operating	Tube side hydrotest	Shell side hydrotest
Tube Side	Design Pressure (kPa)	7,700.01	10,304.84	0
	Operating Pressure (kPa)	7,700.01	N/A	N/A
	External Design Pressure (kPa)	0	N/A	N/A
	Tubesheet Static Pressure (kPa)	0	9.8	0
	Design temperature (°C)	85	25	25
Shell Side	Design Pressure (kPa)	7,700.01	0	10,350.09
	Operating Pressure (kPa)	7,700.01	N/A	N/A
	External Design Pressure (kPa)	0	N/A	N/A
	Tubesheet Static Pressure (kPa)	0	0	9.55
	Design temperature (°C)	85	25	25
Tubes	Design temperature (°C)	85	25	25
	Mean temperature (°C)	35.01	25	25
	α_T (mm/mm/°C)	1.17E-05	1.16E-05	1.16E-05
	E_t (MPa)	201.47E+03	202E+03	202E+03
	S_t (MPa)	92.4	161.1	161.1
	S_y (MPa)	165	179	179
Shell	Mean temperature (°C)	-3.55	25	25
	α_s (mm/mm/°C)	1.15E-05	1.16E-05	1.16E-05
	E_s (MPa)	204E+03	202E+03	202E+03
	S_s (MPa)	138	235.8	235.8
Tubesheet	Design temperature (°C)	85	25	25
	Mean temperature (°C)	35.01	25	25
	E (MPa)	201.47E+03	202E+03	202E+03
	S (MPa)	138	223.2	223.2

Materials and Gaskets Summary

Materials And Gaskets				
Part	Quantity	Size	Material	Gasket
Front ellipsoidal head	1	700.00 ID x 24 mm min thk	SA-516 70	-
Front channel cylinder	1	700.00 ID x 25 thk x 600.00 mm	SA-516 70	-
Tube Side Flange (front)	1	970.00 OD x 115 mm thk	SA-105	833.00 OD x 807.00 ID x 4.45 mm thk
Front tubesheet	1	970.00 OD x 130 mm thk	SA-350 LF2 Cl 1	
Shell Side Flange (front)	1	970.00 OD x 115 mm thk	SA-105	833.00 OD x 807.00 ID x 4.45 mm thk
Front Tubesheet flange bolts	32	1.5 in dia. stud x 450.00 mm long	SA-193 B7	-
Tubes	537	19.05 OD x 2.77 nom wall (2.42 min) x 12000.00 mm	SA-179 Smls. Tube	-
Shell cylinder	1	700.00 ID x 25 mm thk x 11390.71 mm	SA-516 70	-
Shell Side Flange (rear)	1	970.00 OD x 115 mm thk	SA-105	Flexitallic Spiral Wound CG 304 S.S. 833.00 OD x 807.00 ID x 4.45 mm thk
Rear tubesheet	1	970.00 OD x 130 mm thk	SA-350 LF2 Cl 1	
Tube Side Flange (rear)	1	970.00 OD x 115 mm thk	SA-105	Flexitallic Spiral Wound CG 304 S.S. 833.00 OD x 807.00 ID x 4.45 mm thk
Rear Tubesheet flange bolts	32	1.5 in dia. stud x 450.00 mm long	SA-193 B7	-
Rear channel cylinder	1	700.00 ID x 25 thk x 600.00 mm	SA-516 70	-
Rear ellipsoidal head	1	700.00 ID x 24 mm min thk	SA-516 70	-

Nozzle Materials And Gaskets				
Part	Quantity	Size	Material	Gasket
8" Two Nozzles (N1 A/B)	1	8 in 600# WN	A105	-
	1	NPS 8 Sch 80 (XS) DN 200	SA-106 B Smls. Pipe	
	1	219.08 ID x 75.00 wide x 25 mm thk pad	SA-516 70	
Bolts for 8" Two Nozzles (N1 A/B)	12	1.125 in dia. stud x 196.85 mm long	SA-193 B7	
6" Two Nozzles (N3 A/B)	1	6 in 600# WN	A105	-
	1	NPS 6 Sch 80 (XS) DN 150	SA-106 B Smls. Pipe	
	1	168.28 ID x 75.00 wide x 20 mm thk pad	SA-516 70	
Bolts for 6" Two Nozzles (N3 A/B)	12	1 in dia. stud x 171.45 mm long	SA-193 B7	
6" Two Nozzles (N4 A/B)	1	6 in 600# WN	A105	-
	1	NPS 6 Sch 80 (XS) DN 150	SA-106 B Smls. Pipe	
	1	168.28 ID x 75.00 wide x 20 mm thk pad	SA-516 70	
Bolts for 6" Two Nozzles (N4 A/B)	12	1 in dia. stud x 171.45 mm long	SA-193 B7	
8" Two Nozzles (N9)	1	8 in 600# WN	A105	-
	1	NPS 8 Sch 80 (XS) DN 200	SA-106 B Smls. Pipe	
	1	219.08 ID x 75.00 wide x 25 mm thk pad	SA-516 70	
Bolts for 8" Two Nozzles (N9)	12	1.125 in dia. stud x 196.85 mm long	SA-193 B7	

TEMA A.22 Shell Longitudinal Stress, Corroded

(+)$S_{s, max}$ = 51.162 MPa, (-)$S_{s, max}$ = 0 MPa	The shell longitudinal stresses are not excessive.

Equations used	$P_l = P_t - P_t'$	P_t' is from A.154	
	$P_s^* = P_l$		
	$P_s^* = P_s'$	P_s' is from A.153	
	$P_s^* = -P_d$	P_d is from A.151	
	$P_s^* = P_l + P_s'$		
	$P_s^* = P_l - P_d$		
	$P_s^* = P_s' - P_d$		
	$P_s^* = P_l + P_s' - P_d$	$S_s = C_s*(D_o - t_s)*P_s^* / (4*t_s)$	Allowable Stress (+/-)

Operating	P_l = 7,700.01 - 5,635.08 = 2,064.93		$S_s(+)$ = 1*(750 - 22)*6.18 / (4*22) = 51.162 MPa	138 MPa
	P_s^* = 2,064.93	C_s = 1		
P_d = -5,247.73	P_s^* = 4,119.53	C_s = 1		
P_s' = 4,119.53	P_s^* = --5,247.73	C_s = 0.5		
P_t' = 5,635.08	P_s^* = 2,064.93 + 4,119.53 = 6,184.46	C_s = 1	all stresses are tensile	
	P_s^* = 2,064.93 - -5,247.73 = 7,312.66	C_s = 0.5		
	P_s^* = 4,119.53 - -5,247.73 = 9,367.26	C_s = 0.5		
	P_s^* = 2,064.93 + 4,119.53 - -5,247.73 = 11,432.19	C_s = 0.5		

TEMA A.23 Tube Longitudinal Stress - Periphery Of Bundle, Corroded

$(+)S_{t,\ max}$ = 26.092 MPa, $(-)S_{t,\ max}$ = -81.336 MPa			***The tube longitudinal stress is excessive.***	
Equations used	$P_2 = P_t' - (f_t*P_t/F_q)$		P_t' and f_t are from A.154	F_q is from A.151
	$P_3 = P_s' - (f_s*P_s/F_q)$		P_s' and f_s are from A.153	
	$P_t^* = P_2$			
	$P_t^* = -P_3$			
	$P_t^* = P_d$		P_d is from A.151	
	$P_t^* = P_2 - P_3$			
	$P_t^* = P_2 + P_d$			
	$P_t^* = -P_3 + P_d$			
	$P_t^* = P_2 - P_3 + P_d$		$S_t = C_t*F_q*P_t^{*}*G^2/(4*N*t_t*(d_o - t_t))$	Allowable Stress (+/-)
Operating F_q = 12.65 P_d = -5,247.73 P_s' = 4,119.53 P_t' = 5,635.08 P_s = 7,700.01 P_t = 7,700.01	P_2 = 5,635.08 - (0.8543*7,700.01/1.834) = 2,048.23		$S_t(+)$ = 1*1.834*2.05*820.25^2/(4*537*2.77*(19.05 - 2.77)) = 26.092 MPa	92.4 MPa
	P_3 = 4,119.53 - (0.7104*7,700.01/1.834) = 1,137.13			
	P_t^* = 2,048.23	C_t = 1		
	P_t^* = -1,137.13	C_t = 1		
	P_t^* = -5,247.73	C_t = 1		
	P_t^* = 2,048.23 - 1,137.13 = 911.1	C_t = 1	$S_t(-)$ = 1*1.834*-6.38*820.25^2/(4*537*2.77*(19.05 - 2.77)) = -81.336 MPa ***The stress is excessive***	54.103 MPa A.24
	P_t^* = 2,048.23 + -5,247.73 = -3,199.5	C_t = 1		
	P_t^* = -1,137.13 + -5,247.73 = -6,384.86	C_t = 1		
	P_t^* = -1,137.13 + -5,247.73 = -4,336.63	C_t = 1		

TEMA A.25 Tube To Tubesheet Joint Loads - Periphery Of Bundle, Corroded

Equations used	$W_j = \pi*F_q*P_t^{*}*G^2/(4*N)$	F_q is from A.151
	$P_t^* = P_2$	P_2 and P_3 are from A.23
	$P_t^* = -P_3$	
	$P_t^* = P_2 - P_3$	
	$L_{max} = A_t*S_a*f_e*f_r*f_y$	L_{max} is the allowable load from ASME VIII-1, Apendix A-2 Joint Type f, welded, a < 1.4t, and expanded, enhanced with two or more grooves
Operating $W_j <= L_{max}$ indicates the joint strength is adequate for the Corroded condition.	$W_j = \pi$*1.834*2.05*820.25^2/(4*537) = 3,696.51 N	
	L_{max} = 100*1.4167*92.4*1*0.75*1 = 9,817.87 N	$f_y = S_{yTS}/S_{yTube}$ = 33,358.6811/23,931.2277 = 1.3939, f_y = 1

TEMA A.151 Equivalent Differential Expansion Pressure, Corroded, Actual Thickness		
Equations used	J = 1 for shells without expansion joints.	
	$K = E_s*t_s*(D_o - t_s) / (E_t*t_t*N*(d - t_t))$	
	$\Delta L = L_t*(\alpha_s*(T_m\text{-}70) - \alpha_T*(t_m\text{-}70))$	from T-4.5
	$F_q = 0.25 + (F - 0.6)*((300*t_s*E_s/(K*L*E))*(G/T)^3)^{0.25}$	
	$P_d = 4*J*E_s*t_s*(\Delta L/L_t)/((D_o - 3*t_s)*(1 + J*K*F_q))$	
Operating	K = 203,998.499*22*(750 - 22) / (201,466.137*2.77*537*(19.05 - 2.77)) = 0.6697	
	ΔL = 12,000*(6.3889E-06*(25.61-70) - 6.4723E-06*(95.018-70)) = -5.35	
	$\mathbf{F_q}$ = 0.25 + (1 - 0.6)*((300*22*203,998.499/(0.6697*11,746*201,466.137))*(820.25/124) $^3)^{0.25}$ **= 1.834**	
	$\mathbf{P_d}$ = 1000*4*1*203,998.5*22*(-5.35/12,000)/((750 - 3*22)*(1 + 1*0.6697*1.834)) = **-5,247.73 kPa**	

TEMA A.153 Effective Shell Side Design Pressure For Bending, Corroded, Actual Thickness			
Equations used	$f_s = 1 - N*(d_o/G)^2 = 1 - 537*(19.05/820.25)^2 = 0.7104$		
	$P_s' = P_s*(0.4*J*(1.5 + K*(1.5 + f_s)) - ((1 - J)/2)*(D_j^2/G^2 - 1))/(1 + J*K*F_q)$		J, K, F_q are from A.151
	P = greatest absolute value of P_1 through P_6	$P_1 = (P_s' - P_d)/2$	P_d is from A.151
		$P_2 = P_s'$	
		$P_3 = P_{Bs}$	P_{Bs} = 0 (bolt moment not present)
		$P_4 = (P_s' - P_d - P_{Bs})/2$	
		$P_5 = (P_{Bs} + P_d)/2$	
		$P_6 = P_s' - P_{Bs}$	
Operating	P_s' = 7,700.01*(0.4*1*(1.5 + 0.6697*(1.5 + 0.7104)) - ((1 - 1)/2)*(820.25^2/820.25^2 - 1))/(1 + 1*0.6697*1.834) = 4,119.53 kPa		
	P = **4,683.63 kPa** P_{Bs} = 0 P_d = -5,247.73	P_1 = (4,119.53 - -5,247.73)/2 = 4,683.63 kPa	
		P_2 = 4,119.53 kPa	
		P_3 = 0 kPa	
		P_4 = (4,119.53 - -5,247.73 - 0)/2 = 4,683.63 kPa	
		P_5 = (0 + -5,247.73)/2 = -2,623.87 kPa	
		P_6 = 4,119.53 - 0 = 4,119.53 kPa	

TEMA A.154 Effective Tube Side Design Pressure For Bending, Corroded, Actual Thickness

Equations used	$f_t = 1 - N*((d_o-2*t_t)/G)^2 = 1 - 537*((19.05-2*2.77)/820.25)^2 = 0.8543$			
	$P_t' = P_t*((1 + 0.4*J*K*(1.5 + f_t))/(1 + J*K*F_q))$			J, K, F_q are from A.151
	P = greatest absolute value of	when P_s' is positive	$P_1 = (P_t' + P_{Bt} + P_d)/2$	P_d is from A.151
			$P_2 = P_t' + P_{Bt}$	P_{Bt} = 0 (bolt moment not present)
		when P_s' is negative	$P_1 = (P_t' - P_s' + P_{Bt} + P_d)/2$	P_s' is from A.153
			$P_2 = P_t' - P_s' + P_{Bt}$	
Operating	$P_t' = 7,700.01*((1 + 0.4*1*0.6697*(1.5 + 0.8543))/(1 + 1*0.6697*1.834)) = 5,635.08$ kPa			
	P = **5,635.08 kPa**		$P_1 = (5,635.08 + 0 + -5,247.73)/2 = 193.68$ kPa	
	$P_s' = 4,119.53$ $P_d = -5,247.73$ $P_{Bt} = 0$		$P_2 = 5,635.08 + 0 = 5,635.08$ kPa	

TEMA A.24 Allowable Tube Compressive Stress - Periphery Of Bundle, Corroded

Equations used	$r = 0.25*(d_o^2 + (d_o - 2*t_t)^2)^{0.5} = 0.25*(19.05^2 + (19.05 - 2*2.77)^2)^{0.5} = 5.84$	
	$F_s = 3.25 - 0.5*F_q$, where $1.25 \le F_s \le 2$	F_q is from A.151
	$C_c = (2*\pi^2*E_t/S_y)^{0.5}$	$k*l/r = 0.8*780/5.84 = 106.8755$
	$S_c = (S_y/F_s)*(1 - (k*l/r)/(2*C_c))$	when $C_c > k*l/r$
	$S_c = \pi^2*E_t/(F_s*(k*l/r)^2)$	when $C_c <= k*l/r$
Operating	$F_s = 3.25 - 0.5*1.834 = 2.333$	$F_s = 2$
	$C_c = (2*\pi^2*201,466.137/165)^{0.5} = 155.2473$	
	$S_c = (165/2)*(1 - (0.8*780/5.84)/(2*155.2473)) = 54.103$ MPa	$C_c > 106.8755$

TEMA A.22 Shell Longitudinal Stress, New

$(+)S_{s,\ max}$ = 45.284 MPa, $(-)S_{s,\ max}$ = 0 MPa			The shell longitudinal stresses are not excessive.	
Equations used	$P_l = P_t - P_t'$		P_t' is from A.154	
	$P_s^* = P_l$			
	$P_s^* = P_s'$		P_s' is from A.153	
	$P_s^* = -P_d$		P_d is from A.151	
	$P_s^* = P_l + P_s'$			
	$P_s^* = P_l - P_d$			
	$P_s^* = P_s' - P_d$			
	$P_s^* = P_l + P_s' - P_d$		$S_s = C_s*(D_o - t_s)*P_s^* / (4*t_s)$	Allowable Stress (+/-)
Operating	P_l = 7,700.01 - 5,616.37 = 2,083.64		$S_s(+)$ = 1*(750 - 25)*6.25 / (4*25) = 45.284 MPa	138 MPa
	P_s^* = 2,083.64	C_s = 1		
P_d = -5,730.91	P_s^* = 4,162.41	C_s = 1		
P_s' = 4,162.41	P_s^* = --5,730.91	C_s = 0.5		
P_t' = 5,616.37	P_s^* = 2,083.64 + 4,162.41 = 6,246.05	C_s = 1	all stresses are tensile	
	P_s^* = 2,083.64 - -5,730.91 = 7,814.56	C_s = 0.5		
	P_s^* = 4,162.41 - -5,730.91 = 9,893.32	C_s = 0.5		
	P_s^* = 2,083.64 + 4,162.41 - -5,730.91 = 11,976.96	C_s = 0.5		
Tube side hydrotest	P_l = 10,314.63 - 7,538.32 = 2,776.31		$S_s(+)$ = 1*(750 - 25)*2.78 / (4*25) = 20.128 MPa	235.8 MPa
	P_s^* = 2,776.31	C_s = 1		
P_d = 0	P_s^* = 0	C_s = 1		
P_s' = 0	P_s^* = -0	C_s = 1		
P_t' = 7,538.32	P_s^* = 2,776.31 + 0 = 2,776.31	C_s = 1	all stresses are tensile	
	P_s^* = 2,776.31 - 0 = 2,776.31	C_s = 0.5		
	P_s^* = 0 - 0 = 0	C_s = 1		
	P_s^* = 2,776.31 + 0 - 0 = 2,776.31	C_s = 0.5		
Shell side hydrotest	P_l = 0 - 0 = 0		$S_s(+)$ = 1*(750 - 25)*5.6 / (4*25) = 40.625 MPa	235.8 MPa
	P_s^* = 0	C_s = 1		
P_d = 0	P_s^* = 5,603.41	C_s = 1		
P_s' = 5,603.41	P_s^* = -0	C_s = 1		
P_t' = 0	P_s^* = 0 + 5,603.41 = 5,603.41	C_s = 1	all stresses are tensile	
	P_s^* = 0 - 0 = 0	C_s = 1		
	P_s^* = 5,603.41 - 0 = 5,603.41	C_s = 0.5		
	P_s^* = 0 + 5,603.41 - 0 = 5,603.41	C_s = 0.5		

TEMA A.23 Tube Longitudinal Stress - Periphery Of Bundle, New

$(+)S_{t,\ max}$ = 32.027 MPa, $(-)S_{t,\ max}$ = -84.369 MPa

The tube longitudinal stress is excessive.

	Equation	Source	
Equations used	$P_2 = P_t' - (f_t*P_t/F_q)$	P_t' and f_t are from A.154	F_q is from A.151
	$P_3 = P_s' - (f_s*P_s/F_q)$	P_s' and f_s are from A.153	
	$P_t^* = P_2$		
	$P_t^* = -P_3$		
	$P_t^* = P_d$	P_d is from A.151	
	$P_t^* = P_2 - P_3$		
	$P_t^* = P_2 + P_d$		
	$P_t^* = -P_3 + P_d$		
	$P_t^* = P_2 - P_3 + P_d$	$S_t = C_t*F_q*P_t^{*}*G^2/(4*N*t_t*(d_o - t_t))$	Allowable Stress (+/-)

Case	Equation	C_t	Stress	Allowable Stress
Operating	P_2 = 5,616.37 - (0.8543*7,700.01/1.7806) = 1,922		$S_t(+)$ = 1*1.7806*1.92*820.25^2/(4*537*2.77*(19.05 - 2.77)) = 23.771 MPa	92.4 MPa
F_q = 12.28	P_3 = 4,162.41 - (0.7104*7,700.01/1.7806) = 1,090.61			
P_d = -5,730.91	P_t^* = 1,922	C_t = 1		
P_s' = 4,162.41	P_t^* = -1,090.61	C_t = 1		
P_t' = 5,616.37	P_t^* = -5,730.91	C_t = 1		
P_s = 7,700.01	P_t^* = 1,922 - 1,090.61 = 831.39	C_t = 1	$S_t(-)$ = 1*1.7806*-6.82*820.25^2/(4*537*2.77*(19.05 - 2.77)) = -84.369 MPa ***The stress is excessive***	54.103 MPa A.24
P_t = 7,700.01	P_t^* = 1,922 + -5,730.91 = -3,808.92	C_t = 1		
	P_t^* = -1,090.61 + -5,730.91 = -6,821.52	C_t = 1		
	P_t^* = -1,090.61 + -5,730.91 = -4,899.52	C_t = 1		
Tube side hydrotest	P_2 = 7,538.32 - (0.8543*10,314.63/1.7806) = 2,589.49		$S_t(+)$ = 1*1.7806*2.59*820.25^2/(4*537*2.77*(19.05 - 2.77)) = 32.027 MPa	161.1 MPa
F_q = 12.28	P_3 = 0 - (0.7104*0/1.7806) = 0			
P_d = 0	P_t^* = 2,589.49	C_t = 1		
P_s' = 0	P_t^* = -0	C_t = 1		
P_t' = 7,538.32	P_t^* = 0	C_t = 1		
P_s = 0	P_t^* = 2,589.49 - 0 = 2,589.49	C_t = 1	all stresses are tensile	
P_t = 10,314.63	P_t^* = 2,589.49 + 0 = 2,589.49	C_t = 0.5		
	P_t^* = -0 + 0 = 0	C_t = 1		
	P_t^* = -0 + 0 = 2,589.49	C_t = 0.5		
Shell side hydrotest	P_2 = 0 - (0.8543*0/1.7806) = 0		all stresses are compressive	
F_q = 12.28	P_3 = 5,603.41 - (0.7104*10,359.65/1.7806) = 1,470.58			
P_d = 0	P_t^* = 0	C_t = 1		
P_s' = 5,603.41	P_t^* = -1,470.58	C_t = 1		
P_t' = 0	P_t^* = 0	C_t = 1		
P_s = 10,359.65	P_t^* = 0 - 1,470.58 = -1,470.58	C_t = 1	$S_t(-)$ = 1*1.7806*-1.47*820.25^2/(4*537*2.77*(19.05 - 2.77)) = -18.188 MPa	57.455 MPa A.24
P_t = 0	P_t^* = 0 + 0 = 0	C_t = 1		
	P_t^* = -1,470.58 + 0 = -1,470.58	C_t = 1		
	P_t^* = -1,470.58 + 0 = -1,470.58	C_t = 1		

TEMA A.25 Tube To Tubesheet Joint Loads - Periphery Of Bundle, New

Equations used	$W_j = \pi * F_q * P_t^* * G^2/(4*N)$	F_q is from A.151
	$P_t^* = P_2$	P_2 and P_3 are from A.23
	$P_t^* = -P_3$	
	$P_t^* = P_2 - P_3$	
	$L_{max} = A_t * S_a * f_e * f_r * f_y$	L_{max} is the allowable load from ASME VIII-1, Apendix A-2 Joint Type f, welded, a < 1.4t, and expanded, enhanced with two or more grooves
Operating	$W_j = \pi*1.7806*1.92*820.25^2/(4*537) = 3{,}367.74$ N	
$W_j <= L_{max}$ indicates the joint strength is adequate for the New condition.	$L_{max} = 100*1.4167*92.4*1*0.75*1 = 9{,}817.87$ N	$f_y = S_{yTS}/S_{yTube} = 33{,}358.6811/23{,}931.2277 = 1.3939$, $f_y = 1$
Tube side hydrotest	$W_j = \pi*1.7806*2.59*820.25^2/(4*537) = 4{,}537.32$ N	
$W_j <= L_{max}$ indicates the joint strength is adequate for the New condition.	$L_{max} = 100*1.4167*161.1*1*0.75*1 = 17{,}117.52$ N	$f_y = S_{yTS}/S_{yTube} = 35{,}969.3605/25{,}961.7562 = 1.3855$, $f_y = 1$
Shell side hydrotest	$W_j = \pi*1.7806*1.47*820.25^2/(4*537) = 2{,}576.77$ N	
$W_j <= L_{max}$ indicates the joint strength is adequate for the New condition.	$L_{max} = 100*1.4167*161.1*1*0.75*1 = 17{,}117.52$ N	$f_y = S_{yTS}/S_{yTube} = 35{,}969.3605/25{,}961.7562 = 1.3855$, $f_y = 1$

TEMA A.151 Equivalent Differential Expansion Pressure, New, Actual Thickness

Equations used	J = 1 for shells without expansion joints.	
	$K = E_s*t_s*(D_o - t_s) / (E_t*t_t*N*(d - t_t))$	
	$\Delta L = L_t*(\alpha_s*(T_m\text{-}70) - \alpha_T*(t_m\text{-}70))$	from T-4.5
	$F_q = 0.25 + (F - 0.6)*((300*t_s*E_s/(K*L*E))*(G/T)^3)^{0.25}$	
	$P_d = 4*J*E_s*t_s*(\Delta L/L_t)/((D_o - 3*t_s)*(1 + J*K*F_q))$	
Operating	$K = 203{,}998.499*25*(750 - 25) / (201{,}466.137*2.77*537*(19.05 - 2.77)) = 0.7579$	
	$\Delta L = 12{,}000*(6.3889E\text{-}06*(25.61\text{-}70) - 6.4723E\text{-}06*(95.018\text{-}70)) = -5.35$	
	$\mathbf{F_q} = 0.25 + (1 - 0.6)*((300*25*203{,}998.499/(0.7579*11{,}740*201{,}466.137))*(820.25/130)^3)^{0.25}$ **= 1.7806**	
	$\mathbf{P_d} = 1000*4*1*203{,}998.5*25*(-5.35/12{,}000)/((750 - 3*25)*(1 + 1*0.7579*1.7806)) =$ **-5,730.91 kPa**	
Tube side hydrotest	$K = 201{,}999.998*25*(750 - 25) / (201{,}999.998*2.77*537*(19.05 - 2.77)) = 0.7485$	
	$\Delta L = 12{,}000*(6.4167E\text{-}06*(77\text{-}70) - 6.4167E\text{-}06*(77\text{-}70)) = 0$	
	$\mathbf{F_q} = 0.25 + (1 - 0.6)*((300*25*201{,}999.998/(0.7485*11{,}740*201{,}999.998))*(820.25/130)^3)^{0.25}$ **= 1.7806**	
	$\mathbf{P_d} = 1000*4*1*202{,}000*25*(0/12{,}000)/((750 - 3*25)*(1 + 1*0.7485*1.7806)) =$ **0 kPa**	
Shell side hydrotest	$K = 201{,}999.998*25*(750 - 25) / (201{,}999.998*2.77*537*(19.05 - 2.77)) = 0.7485$	
	$\Delta L = 12{,}000*(6.4167E\text{-}06*(77\text{-}70) - 6.4167E\text{-}06*(77\text{-}70)) = 0$	
	$\mathbf{F_q} = 0.25 + (1 - 0.6)*((300*25*201{,}999.998/(0.7485*11{,}740*201{,}999.998))*(820.25/130)^3)^{0.25}$ **= 1.7806**	
	$\mathbf{P_d} = 1000*4*1*202{,}000*25*(0/12{,}000)/((750 - 3*25)*(1 + 1*0.7485*1.7806)) =$ **0 kPa**	

TEMA A.152 Equivalent Bolting Pressure, New	
Equations used	P_{Bt} = 6.2*M_1/(F^2*G^3)
	P_{Bs} = 6.2*M_2/(F^2*G^3)
Tube side hydrotest	P_{Bt} = 6.2*1e6*418,002.5/(1^2*820.25^3) = 4,695.97 kPa
	P_{Bs} = 6.2*1e6*231,868.2/(1^2*820.25^3) = 2,604.88 kPa
Shell side hydrotest	P_{Bt} = 6.2*1e6*419,826.7/(1^2*820.25^3) = 4,716.46 kPa
	P_{Bs} = 6.2*1e6*232,880.1/(1^2*820.25^3) = 2,616.25 kPa

TEMA A.153 Effective Shell Side Design Pressure For Bending, New, Actual Thickness

Equations used	$f_s = 1 - N*(d_o/G)^2 = 1 - 537*(19.05/820.25)^2 = 0.7104$		
	$P_s' = P_s*(0.4*J*(1.5 + K*(1.5 + f_s)) - ((1 - J)/2)*(D_j^2/G^2 - 1))/(1 + J*K*F_q)$		J, K, F_q are from A.151
	P = greatest absolute value of P_1 through P_6	$P_1 = (P_s' - P_d)/2$	P_d is from A.151
		$P_2 = P_s'$	
		$P_3 = P_{Bs}$	P_{Bs} is from A.152
		$P_4 = (P_s' - P_d - P_{Bs})/2$	
		$P_5 = (P_{Bs} + P_d)/2$	
		$P_6 = P_s' - P_{Bs}$	
Operating	P_s' = 7,700.01*(0.4*1*(1.5 + 0.7579*(1.5 + 0.7104)) - ((1 - 1)/2) *(820.25²/820.25² - 1))/(1 + 1*0.7579*1.7806) = 4,162.41 kPa		
	P = **4,946.66 kPa** P_{Bs} = 0 P_d = -5,730.91	P_1 = (4,162.41 - -5,730.91)/2 = 4,946.66 kPa	
		P_2 = 4,162.41 kPa	
		P_3 = 0 kPa	
		P_4 = (4,162.41 - -5,730.91 - 0)/2 = 4,946.66 kPa	
		P_5 = (0 + -5,730.91)/2 = -2,865.46 kPa	
		P_6 = 4,162.41 - 0 = 4,162.41 kPa	
Tube side hydrotest	P_s' = 0*(0.4*1*(1.5 + 0.7485*(1.5 + 0.7104)) - ((1 - 1)/2) *(820.25²/820.25² - 1))/(1 + 1*0.7485*1.7806) = 0 kPa		
	P = **2,604.88 kPa** P_{Bs} = 2,604.88 P_d = 0	P_1 = (0 - 0)/2 = 0 kPa	
		P_2 = 0 kPa	
		P_3 = 2,604.88 kPa	
		P_4 = (0 - 0 - 2,604.88)/2 = -1,302.44 kPa	
		P_5 = (2,604.88 + 0)/2 = 1,302.44 kPa	
		P_6 = 0 - 2,604.88 = -2,604.88 kPa	
Shell side hydrotest	P_s' = 10,359.65*(0.4*1*(1.5 + 0.7485*(1.5 + 0.7104)) - ((1 - 1)/2) *(820.25²/820.25² - 1))/(1 + 1*0.7485*1.7806) = 5,603.41 kPa		
	P = **5,603.41 kPa** P_{Bs} = 2,616.25 P_d = 0	P_1 = (5,603.41 - 0)/2 = 2,801.7 kPa	
		P_2 = 5,603.41 kPa	
		P_3 = 2,616.25 kPa	
		P_4 = (5,603.41 - 0 - 2,616.25)/2 = 1,493.58 kPa	
		P_5 = (2,616.25 + 0)/2 = 1,308.12 kPa	
		P_6 = 5,603.41 - 2,616.25 = 2,987.16 kPa	

TEMA A.154 Effective Tube Side Design Pressure For Bending, New, Actual Thickness				
Equations used	$f_t = 1 - N*((d_o-2*t_t)/G)^2 = 1 - 537*((19.05-2*2.77)/820.25)^2 = 0.8543$			
	$P_t' = P_t*((1 + 0.4*J*K*(1.5 + f_t))/(1 + J*K*F_q))$			J, K, F_q are from A.151
	P = greatest absolute value of	when P_s' is positive	$P_1 = (P_t' + P_{Bt} + P_d)/2$	P_d is from A.151
			$P_2 = P_t' + P_{Bt}$	P_{Bt} is from A.152
		when P_s' is negative	$P_1 = (P_t' - P_s' + P_{Bt} + P_d)/2$	P_s' is from A.153
			$P_2 = P_t' - P_s' + P_{Bt}$	
Operating	P_t' = 7,700.01*((1 + 0.4*1*0.7579*(1.5 + 0.8543))/(1 + 1*0.7579*1.7806)) = 5,616.37 kPa			
	P = **5,616.37 kPa** P_s' = 4,162.41 P_d = -5,730.91 P_{Bt} = 0		P_1 = (5,616.37 + 0 + -5,730.91)/2 = -57.27 kPa	
			P_2 = 5,616.37 + 0 = 5,616.37 kPa	
Tube side hydrotest	P_t' = 10,314.63*((1 + 0.4*1*0.7485*(1.5 + 0.8543))/(1 + 1*0.7485*1.7806)) = 7,538.32 kPa			
	P = **12,234.29 kPa** P_s' = 0 P_d = 0 P_{Bt} = 4,695.97		P_1 = (7,538.32 + 4,695.97 + 0)/2 = 6,117.15 kPa	
			P_2 = 7,538.32 + 4,695.97 = 12,234.29 kPa	
Shell side hydrotest	P_t' = 0*((1 + 0.4*1*0.7485*(1.5 + 0.8543))/(1 + 1*0.7485*1.7806)) = 0 kPa			
	P = **4,716.46 kPa** P_s' = 5,603.41 P_d = 0 P_{Bt} = 4,716.46		P_1 = (0 + 4,716.46 + 0)/2 = 2,358.23 kPa	
			P_2 = 0 + 4,716.46 = 4,716.46 kPa	

TEMA A.24 Allowable Tube Compressive Stress - Periphery Of Bundle, New		
Equations used	$r = 0.25*(d_o^2 + (d_o - 2*t_t)^2)^{0.5} = 0.25*(19.05^2 + (19.05 - 2*2.77)^2)^{0.5} = 5.84$	
	$F_s = 3.25 - 0.5*F_q$, where $1.25 \le F_s \le 2$	F_q is from A.151
	$C_c = (2*\pi^2*E_t/S_y)^{0.5}$	k*l/r = 0.8*780/5.84 = 106.8755
	$S_c = (S_y/F_s)*(1 - (k*l/r)/(2*C_c))$	when C_c > k*l/r
	$S_c = \pi^2*E_t/(F_s*(k*l/r)^2)$	when C_c <= k*l/r
Operating	F_s = 3.25 - 0.5*1.7806 = 2.3597	F_s = 2
	$C_c = (2*\pi^2*201,466.137/165)^{0.5}$ = 155.2473	
	S_c = (165/2)*(1 - (0.8*780/5.84)/(2*155.2473)) = 54.103 MPa	C_c > 106.8755
Tube side hydrotest	F_s = 3.25 - 0.5*1.7806 = 2.3597	F_s = 2
	$C_c = (2*\pi^2*201,999.998/179)^{0.5}$ = 149.2499	
	S_c = (179/2)*(1 - (0.8*780/5.84)/(2*149.2499)) = 57.455 MPa	C_c > 106.8755
Shell side hydrotest	F_s = 3.25 - 0.5*1.7806 = 2.3597	F_s = 2
	$C_c = (2*\pi^2*201,999.998/179)^{0.5}$ = 149.2499	
	S_c = (179/2)*(1 - (0.8*780/5.84)/(2*149.2499)) = 57.455 MPa	C_c > 106.8755

Tubes

ASME Section VIII Division 1, 2013 Edition Metric

Component:	Tubes
Material specification:	SA-179 Smls. Tube (II-D Metric p. 6, ln. 11)

Material is impact test exempt per UCS-66(d) (NPS 4 or smaller pipe)

Internal design pressure: P = 7,700.01 kPa @ 85 °C
External design pressure: P_e = 7,700.01 kPa @ 85 °C

Static liquid head:

P_{th} = 9.75 kPa (SG = 1, H_s = 994.78 mm, Horizontal test head)

Corrosion allowance	Inner C = 0 mm	Outer C = 0 mm

Design MDMT = -29 °C	No impact test performed
Rated MDMT = -105 °C	Material is not normalized
	Material is not produced to Fine Grain Practice
	PWHT is not performed

Estimated weight	New = 13.3 kg	corr = 13.3 kg
Capacity	New = 1.72 liters	corr = 1.72 liters

OD	=	19.05 mm
Length L_c	=	12,000 mm
t	=	2.77 mm

Design thickness, (at 85 °C) Appendix 1-1

t = P*R_o / (S*E + 0.40*P) + Corrosion
= 7,700.01*9.52 / (92,400*1.00 + 0.40*7,700.01) + 0
= 0.77 mm

Maximum allowable working pressure, (at 85 °C) Appendix 1-1

P = S*E*t / (R_o - 0.40*t) - P_s
= 92,400*1.00*(2.77*0.875) / (9.52 - 0.40*(2.77*0.875)) - 0
= 26,176.67 kPa

Maximum allowable pressure, (at 25 °C) Appendix 1-1

P = S*E*t / (R_o - 0.40*t)
= 92,400*1.00*(2.77*0.875) / (9.52 - 0.40*(2.77*0.875))
= 26,176.67 kPa

External Pressure, (Corroded & at 85 °C) UG-28(c)

L / D_o = 12,000 / 19.05 = 50.0000
D_o / t = 19.05 / 1.22 = 15.6201
From table G: A = 0.004633
From table CS-1 Metric: B = 90.2068 MPa

P_a = $4*B / (3*(D_o / t))$
= 4*90,206.79 / (3*(19.05 / 1.22))
= 7,700.06 kPa

Design thickness for external pressure P_a = 7,700.06 kPa

t_a = t + Corrosion = 1.22 + 0 = 1.22 mm

Maximum Allowable External Pressure, (Corroded & at 85 °C) UG-28(c)

L / D_o = 12,000 / 19.05 = 50.0000
D_o / t = 19.05 / (2.77*0.875) = 7.8597
From table G: A = 0.018368
From table CS-1 Metric: B = 95.1 MPa
$S_1 = 2*S_e$ = 2*92.4 = 184.8 MPa
$S_2 = 0.90*S_y$ = 0.90*190.2 = 171.18 MPa
$S = \min(S_1, S_2)$ = min(184.8, 171.18) = 171.18 MPa

P_{a1} = $[2.167 / (D_o / t) - 0.08333]*B$
= [2.167 / 7.8597 - 0.08333]*13793.0892
= 18,298.14 kPa

P_{a2} = $(2*S / (D_o / t))*[1 - 1/(D_o / t)]$
= (2*171.18 / 7.8597)*[1 - 1/7.8597]
= 38,016.77 kPa

Maximum Allowable External Pressure = $\min(P_{a1}, P_{a2})$ = 18,298.14 kPa

Tubesheet -- ASME

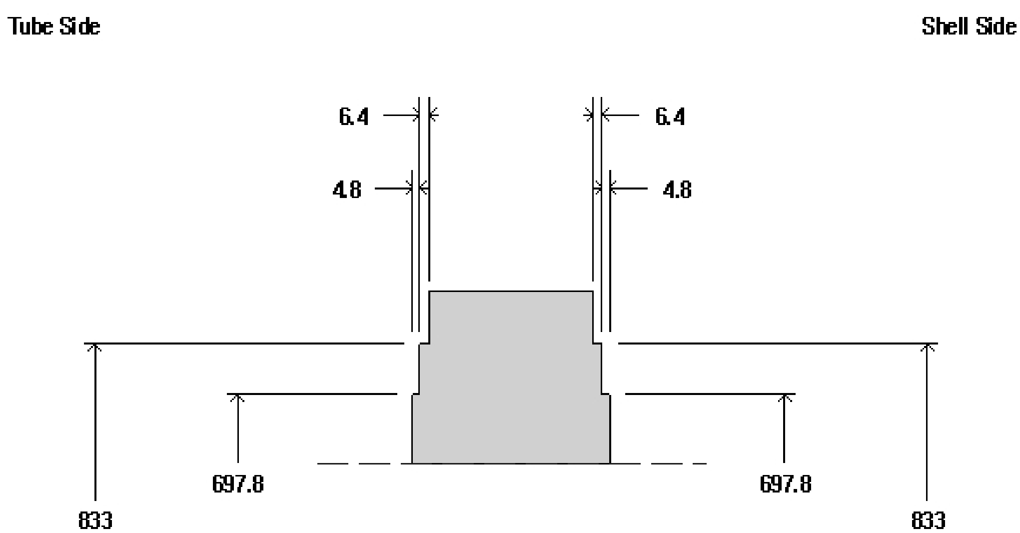
ASME Section VIII Division 1, 2013 Edition Metric

Tubesheet

Type of heat exchanger:	Fixed Both Ends
Type of construction:	Fixed\Stationary tubesheet per Fig. UHX-13.1 Configuration d: both sides gasketed
Simply supported:	No
Tubesheet material specification:	SA-350 LF2 Cl 1 (II-D Metric p. 18, ln. 37)
Tube layout:	Square
Tubesheet outer diameter, A:	970 mm
Tubesheet thickness, h:	130 mm (t_{design} = 116.55 mm)
Number of tubes, N_t:	537
Tube pitch, p:	25.4 mm
Radius to outer tube center, r_o:	335.25 mm
Total area of untubed lanes, A_L:	0 m^2
Pass partition groove depth, h_g:	0 mm
Corrosion allowance shell side , c_s:	3 mm
Corrosion allowance tube side , c_t:	3 mm
Tubesheet poisson's ratio, ν:	0.3
Perimeter of the tube layout, C_p:	2,139.27 mm
Total area enclosed by C_p, A_p:	0.3642 m^2
Consider radial thermal expansion per UHX-13.8:	No

Stepped Tubesheet

Step 1 diameter shell side	833 mm
Step 1 depth shell side	6.4 mm
Step 2 diameter shell side	697.8 mm
Step 2 depth shell side	4.8 mm
Step 1 diameter tube side	833 mm
Step 1 depth tube side	6.4 mm
Step 2 diameter tube side	697.8 mm
Step 2 depth tube side	4.8 mm



Shell

Shell material specification:	SA-516 70 (II-D Metric p. 22, ln. 6)
Shell inner diameter, D_s:	700 mm
Shell thickness, t_s:	25 mm
Shell inner corrosion allowance:	3 mm

Shell outer corrosion allowance: 0 mm
Shell poisson's ratio, ν_s: 0.31
Circumferential weld joint efficiency, $E_{s,w}$: 1

Channel

Channel material specification: SA-516 70 (II-D Metric p. 22, ln. 6)
Channel inner diameter, D_c: 700 mm
Channel thickness, t_c: 25 mm
Channel inner corrosion allowance: 3 mm
Channel outer corrosion allowance: 0 mm
Channel poisson's ratio, ν_c: 0.3

Tubes

Tube material specification: SA-179 Smls. Tube (II-D Metric p. 6, ln. 11)
Tube outer diameter, d_t: 19.05 mm
Tube nominal thickness, t_t: 2.77 mm
Tube minimum thickness, $t_{t,min}$: 2.42 mm
Tube tolerance: 12.5%
Tube length between outer tubesheet faces, L_t: 12,000 mm
Tube inner corrosion allowance: 0 mm
Tube outer corrosion allowance: 0 mm
Tube expansion depth ratio, ρ: 0.85
Tube poisson's ratio, ν_t: 0.3

Flange

Bolt circle diameter, C: 892 mm
Shell side gasket load reaction diameter, G_s: 820.25 mm
Channel side gasket load reaction diameter, G_c: 820.25 mm

Tube Supports

Tube supports present: Yes
Support all tubes: No
Maximum distance from tubesheet to first support: 780 mm
Maximum distance between tube supports: 420 mm

Tube-To-Tubesheet Joints

Calculation method: Appendix A
Joint type: Table A-2 Type f, Welded, a <1.4*t, and expanded, enhanced with two or more grooves

Tube-To-Tubesheet Joint Loads

Summary Tables

Tubesheet Design Thickness Summary	
Condition	**t_{design} (mm)**
Operating	116.5481836
Tube side hydrotest	89.6002329
Shell side hydrotest	71.5611329

Tubesheet Effective Bolt Load		
Condition	**Load Case**	**W^* (N)**
Operating	Load case 1	4,825,175.49
	Load case 2	4,825,175.49
	Load case 3	4,825,175.49
	Load case 5	4,907,137.87
	Load case 6	4,907,137.87
	Load case 7	4,907,137.87
	Load case 8	3,060,400.43
Tube side hydrotest	Load case 1	6,463,614.18
Shell side hydrotest	Load case 2	6,491,822.21

Pressures										
Condition	**Shell Side**					**Tube Side**				
	$P_{sd,max}$ (kPa)	**$P_{sd,min}$ (kPa)**	**P_{sox} (kPa)**	**Static Pressure (kPa)**	**Consider Liquid**	**$P_{td,max}$ (kPa)**	**$P_{td,min}$ (kPa)**	**P_{tox} (kPa)**	**Static Pressure (kPa)**	**Consider Liquid**
Operating	7,700.01	0	7,700.01	0	No	7,700.01	0	7,700.01	0	No
Tube side hydrotest	0	0	-	0	No	10,304.84	0	-	9.8	Yes
Shell side hydrotest	10,350.09	0	-	9.55	Yes	0	0	-	0	No

Temperatures						
Condition	**Tubesheet design T (°C)**	**Shell design T_s (°C)**	**Channel design T_c (°C)**	**Tube design T_t (°C)**	**Shell mean $T_{s,m}$ (°C)**	**Tube mean $T_{t,m}$ (°C)**
Operating	85	85	85	85	-3.55	35.01
Tube side hydrotest	25	25	25	25	25	25
Shell side hydrotest	25	25	25	25	25	25

Material Properties							
Condition	**Component**	**Material**	**Modulus of Elasticity (MPa)**	**Allowable Stress (MPa)**	**Yield Stress (MPa)**	**Mean Coefficient Thermal Expansion**	**Mean Coefficient Thermal Expansion**
Operating	Shell	SA-516 70	E_s = 198,800	S_s = 138	$S_{y,s}$ =242	α'_s = 1.35E-05	$\alpha_{s,m}$ = 1.15E-05
	Channel	SA-516 70	E_c =198,800	S_c =138	$S_{y,c}$ =242	α'_c = 1.33E-05	N/A
	Tubesheet	SA-350 LF2 Cl 1	E =198,800	S =138	S =230	α' = 1.18E-05	N/A
	Tubes	SA-179 Smls. Tube	E_t =198,800	S_t =92.4	$S_{y,t}$ =165	N/A	$\alpha_{t,m}$ = 1.17E-05
			E_{tT} =198,800	S_{tT} =92.4	N/A	N/A	N/A
Tube side hydrotest	Shell	SA-516 70	E_s = 202,000	S_s = 235.8	$S_{y,s}$ =262	α'_s = 1.16E-05	$\alpha_{s,m}$ = 1.16E-05
	Channel	SA-516 70	E_c =202,000	S_c =235.8	$S_{y,c}$ =262	α'_c = 1.16E-05	N/A
	Tubesheet	SA-350 LF2 Cl 1	E =202,000	S =223.2	S =248	α' = 1.16E-05	N/A
	Tubes	SA-179 Smls. Tube	E_t =202,000	S_t =161.1	$S_{y,t}$ =179	N/A	$\alpha_{t,m}$ = 1.16E-05
			E_{tT} =202,000	S_{tT} =161.1	N/A	N/A	N/A
Shell side hydrotest	Shell	SA-516 70	E_s = 202,000	S_s = 235.8	$S_{y,s}$ =262	α'_s = 1.16E-05	$\alpha_{s,m}$ = 1.16E-05
	Channel	SA-516 70	E_c =202,000	S_c =235.8	$S_{y,c}$ =262	α'_c = 1.16E-05	N/A
	Tubesheet	SA-350 LF2 Cl 1	E =202,000	S =223.2	S =248	α' = 1.16E-05	N/A
	Tubes	SA-179 Smls. Tube	E_t =202,000	S_t =161.1	$S_{y,t}$ =179	N/A	$\alpha_{t,m}$ = 1.16E-05
			E_{tT} =202,000	S_{tT} =161.1	N/A	N/A	N/A

Calculations for Operating Condition

Table UHX-13.4-1		
Design Loading Case	**Shell Side Design Pressure, P_s (kPa)**	**Tube Side Design Pressure, P_t (kPa)**
1	0	7,700.01
2	7,700.01	0
3	7,700.01	7,700.01

Table UHX-13.4-2				
Operating Loading Case	Operating Pressure		Axial Mean Metal Temperature	
	Shell Side, P_s (kPa)	Tube Side, P_t (kPa)	Tubes, T_{tm} (°C)	Shell, T_{sm} (°C)
5	0	7,700.01	35.01	-3.55
6	7,700.01	0		
7	7,700.01	7,700.01		
8	0	0		

UHX-9.5			
$h_r = D_E / (3.2*S)*abs(P_s - P_t)$			
Condition Operating			
New or corroded	Load case 1, 2, 5, 6	h_r = 807 / (3.2*138)*abs(0 - 7,700.01) =	14.07
	Load case 3, 7, 8	h_r = 807 / (3.2*138)*abs(7,700.01 - 7,700.01) =	0
Tubesheet Design Thickness to Maintain h_r = 14.07 + 11.2 + 11.2 = 36.47 mm			

UHX-13.5.1 Step 1		
$D_o = 2*r_o + d_t$		
$\mu = (p - d_t) / p$		
$d^* = MAX\{[d_t - 2*t_t*(E_{tT} / E)*(S_{tT} / S)*\rho], [d_t - 2*t_t]\}$		
$p^* = p / (1 - 4*MIN(A_L, 4*D_o*p) / (\pi*D_o^2))^{0.5}$		
$\mu^* = (p^* - d^*) / p^*$		
$h_g' = MAX[(h_g - c_t), 0]$ for pressure load only. For load cases 5, 6, 7, 8 $h_g' = 0$.		
$a_o = D_o / 2$		
$\rho_s = a_s / a_o$		
$\rho_c = a_c / a_o$		
$x_t = 1 - N_t*((d_t - 2*t_t) / (2*a_o))^2$		
$x_s = 1 - N_t*(d_t / (2*a_o))^2$		
Condition Operating		
New or corroded	$D_o = 2*335.25 + 19.05 =$	689.55
New or corroded	$\mu = (25.4 - 19.05) / 25.4 =$	0.25
New	$d^* = MAX\{[19.05 - 2*2.77*(198,800.004 / 198,800.004)*(92.4 / 138)*0.85], [19.05 - 2*2.77]\} =$	15.8970174
Corroded	$d^* = MAX\{[19.05 - 2*2.77*(198,800.004 / 198,800.004)*(92.4 / 138)*0.8669], [19.05 - 2*2.77]\} =$	15.834196
New or corroded	$p^* = 25.4 / (1 - 4*MIN(0, 4*689.55*25.4) / (\pi*689.55^2))^{0.5} =$	25.4
New	$\mu^* = (25.399 - 15.8970174) / 25.399 =$	0.374109
Corroded	$\mu^* = (25.399 - 15.834196) / 25.399 =$	0.376582
	$h_g' =$	0
New or corroded	$a_o = 689.55 / 2 =$	344.78
New or corroded	$\rho_s = 410.13 / 344.78 =$	1.18955
New or corroded	$\rho_c = 410.13 / 344.78 =$	1.18955
New or corroded	$x_s = 1 - 537*(19.05 / (2*344.78))^2 =$	0.590143
New or corroded	$x_t = 1 - 537*((19.05 - 2*2.77) / (2*344.78))^2 =$	0.793864

UHX-13.5.2 Step 2		
$K_s = \pi * t_s * (D_s + t_s) * E_s / L$		
$K_t = \pi * t_t * (d_t - t_t) * E_t / L$		
$K_{s,t} = K_s / (N_t * K_t)$		
$J = 1 / (1 + K_s / K_J)$		
β_s, k_s, λ_s, & δ_s = 0 for configuration d		
β_c, k_c, λ_c, & δ_c = 0 for configuration d		
Condition Operating		
New	$K_s = \pi$*25*(700 + 25)*198,800.004 / 11,740 =	964,219.94
Corroded	$K_s = \pi$*22*(706 + 22)*198,800.004 / 11,746 =	851,589.42
New	$K_t = \pi$*2.77*(19.05 - 2.77)*198,800.004 / 11,740 =	2,399.01
Corroded	$K_t = \pi$*2.77*(19.05 - 2.77)*198,800.004 / 11,746 =	2,397.79
New	$K_{s,t}$ = 964,219.94 / (537*2,399.01) =	0.748462
Corroded	$K_{s,t}$ = 851,589.42 / (537*2,397.79) =	0.661372
New or corroded	J = 1 as no expansion joint used	

UHX-13.5.3 Step 3		
$E^* / E = \alpha_0 + \alpha_1 * \mu^* + \alpha_2 * \mu^{*2} + \alpha_3 * \mu^{*3} + \alpha_4 * \mu^{*4}$		
$\nu^* = \beta_0 + \beta_1 * \mu^* + \beta_2 * \mu^{*2} + \beta_3 * \mu^{*3} + \beta_4 * \mu^{*4}$		
$\eta = (E^* / E) * (1 - \nu^2) / (1 - \nu^{*2})$		
$X_a = [24 * (1 - \nu^{*2}) * N_t * E_t * t_t * (d_t - t_t) * a_o^2 / (E^* * L * h^3)]^{0.25}$		
Condition Operating		
New	h / p = 130 / 25.4 =	5.1183
Corroded	h / p = 124 / 25.4 =	4.8821
New	- from Fig. UHX-11.4(a) E^* / E =	0.4277
Corroded	- from Fig. UHX-11.4(a) E^* / E =	0.4306
New	E^* = 0.4276867*198,800.004 =	85,024.112
Corroded	E^* = 0.4306408*198,800.004 =	85,611.385
New	- from Fig. UHX-11.4(b) ν^* =	0.3192
Corroded	- from Fig. UHX-11.4(b) ν^* =	0.3189
New	$X_a = [24*(1 - 0.3192194^2)*537*198{,}800.004*2.77*(19.05 - 2.77)*344.78^2 / (85{,}024.112*11{,}740*130^3)]^{0.25}$ =	1.54
Corroded	$X_a = [24*(1 - 0.3189337^2)*537*198{,}800.004*2.77*(19.05 - 2.77)*344.78^2 / (85{,}611.385*11{,}746*124^3)]^{0.25}$ =	1.5927
New	Z_d =	0.4098776
Corroded	Z_d =	0.3646518
New	Z_v =	0.1790294
Corroded	Z_v =	0.1776664
New	Z_m =	0.7264957
Corroded	Z_m =	0.7224302
New	Z_w =	0.1790294
Corroded	Z_w =	0.1776664
New	Z_a =	0.5455139
Corroded	Z_a =	0.5696925

UHX-13.5.4 Step 4		
$K = A / D_o$		
$F = ((1 - \nu^*) / E^*)*(\lambda_s + \lambda_c + E*\ln(K))$		
$\Phi = (1 + \nu^*)*F$		
$Q_1 = (\rho_s - 1 - \Phi*Z_v) / (1 + \Phi*Z_m)$		
$Q_{z1} = (Z_d + Q_1*Z_w)*X_a^4 / 2$		
$Q_{z2} = (Z_v + Q_1*Z_m)*X_a^4 / 2$		
$U = [Z_w + (\rho_s - 1)*Z_m]*X_a^4 / (1 +\Phi*Z_m)$		
Condition Operating		
New or corroded	K = 970 / 689.55 =	1.4067145
New	F = ((1 - 0.3192194) / 85,024.112)*(0 + 0 + 198,800,003.54*ln(1.4067)) / 1000 =	0.5432038
Corroded	F = ((1 - 0.3189337) / 85,611.385)*(0 + 0 + 198,800,003.54*ln(1.4067)) / 1000 =	0.539704
New	Φ = (1 + 0.3192194)*0.5432038 =	0.7166051
Corroded	Φ = (1 + 0.3189337)*0.539704 =	0.7118338
New	Q_1 = (1.1895501 - 1 - 0.7166051*0.1790294) / (1 + 0.7166051*0.7264957) =	0.0402843
Corroded	Q_1 = (1.1895501 - 1 - 0.7118338*0.1776664) / (1 + 0.7118338*0.7224302) =	0.0416583
New	Q_{z1} = (0.4098776 + 0.0402843*0.1790294)*1.5400077^4 / 2 =	1.173
Corroded	Q_{z1} = (0.3646518 + 0.0416583*0.1776664)*1.5926952^4 / 2 =	1.197
New	Q_{z2} = (0.1790294 + 0.0402843*0.7264957)*1.5400077^4 / 2 =	0.5858
Corroded	Q_{z2} = (0.1776664 + 0.0416583*0.7224302)*1.5926952^4 / 2 =	0.6684
New	U = [0.1790294 + (1.1895501 - 1)*0.7264957]*1.5400077^4 / (1 +0.7166051*0.7264957) =	1.1716
Corroded	U = [0.1776664 + (1.1895501 - 1)*0.7224302]*1.5926952^4 / (1 +0.7118338*0.7224302) =	1.3369

UHX-13.5.5 Step 5		
$\gamma_b = (G_c - G_s) / D_o$		
Condition Operating		
New or corroded	γ_b = (820.25 - 820.25) / 689.55 =	0

UHX-13.5.5 Step 5			
$\gamma = [\alpha_{t,m}*(T_{t,m} - T_a) - \alpha_{s,m}*(T_{s,m} - T_a)]*L$			
$\omega_s = \rho_s*k_s*\beta_s*\delta_s*(1 + h*\beta_s)$			
$\omega_c = \rho_c*k_c*\beta_c*\delta_c*(1 + h*\beta_c)$			
$\omega_s^* = a_o^2*(\rho_s^2 - 1)*(\rho_s - 1) / 4 - \omega_s$			
$\omega_c^* = a_o^2*[(\rho_c^2 + 1)*(\rho_c - 1) / 4 - (\rho_s - 1) / 2] - \omega_c$			
Condition Operating			
		P_s (kPa)	**P_t (kPa)**
Load Case 1		0	7,700.01
Load Case 2		7,700.01	0
Load Case 3		7,700.01	7,700.01
Load Case 5		0	7,700.01
Load Case 6		7,700.01	0
Load Case 7		7,700.01	7,700.01
Load Case 8		0	0
New	Load case 1, 2, 3	γ =	0
	Load case 5, 6, 7, 8	γ = [1.17E-05*(35.01 - 20) - 1.15E-05*(-3.55 - 20)]*11,740 =	5.2324357
Corroded	Load case 1, 2, 3	γ =	0
	Load case 5, 6, 7, 8	γ = [1.17E-05*(35.01 - 20) - 1.15E-05*(-3.55 - 20)]*11,746 =	5.2351099
New or corroded	All load cases	ω_s = 1.1895501*0.0*0.0*0*(1 + 124*0.0) =	0
New or corroded	All load cases	ω_s^* = 344.78^2*(1.1895501^2 - 1)*(1.1895501 - 1) / 4 - 0.0 =	2,337.8386
New or corroded	All load cases	ω_c = 1.1895501*0.0*0.0*0*(1 + 124*0.0) =	0
New or corroded	All load cases	ω_c^* = 344.78^2*[(1.1895501^2 + 1)*(1.1895501 - 1) / 4 - (1.1895501 - 1) / 2] - 0.0 =	2,337.8386

UHX-13.5.6 Step 6			
$P_s' = (x_s + 2*(1 - x_s)*\nu_t + 2 / K_{s,t}*(D_s / D_o)^2*\nu_s - (\rho_s^2 - 1) / (J*K_{s,t}) - (1 - J)*[D_j^2 - D_s^2] / (2*J*K_{s,t}*D_o^2))*P_s$			
$P_t' = (x_t + 2*(1 - x_t)*\nu_t + 1 / (J*K_{s,t}))*P_t$			
$P_\gamma = N_t*K_t*\gamma / (\pi*a_o^2)$			
$P_W = - U*\gamma_b*W^* / (2*\pi*a_o^2)$			
$P_{rim} = - U / a_o^2*(\omega_s^{*}*P_s - \omega_c^{*}*P_t)$			
$P_e = J*K_{s,t} / (1 + J*K_{s,t}*[Q_{Z1} + (\rho_s - 1)*Q_{Z2}])*(P_s' - P_t' + P_\gamma + P_W + P_{rim})$			
Condition Operating			
New	Load case 1, 5, 8	$P_s' = (0.5901427 + 2*(1 - 0.5901427)*0.3 + 2 / 0.7484617*(700 / 689.55)^2*0.31 - (1.1895501^2 - 1) / (1.0*0.7484617) - (1 - 1.0)*[0^2 - 700^2] / (2*1.0*0.7484617*689.55^2))*0 =$	0
	Load case 2, 3, 6, 7	$P_s' = (0.5901427 + 2*(1 - 0.5901427)*0.3 + 2 / 0.7484617*(700 / 689.55)^2*0.31 - (1.1895501^2 - 1) / (1.0*0.7484617) - (1 - 1.0)*[0^2 - 700^2] / (2*1.0*0.7484617*689.55^2))*7{,}700.01 =$	8,741.14
Corroded	Load case 1, 5, 8	$P_s' = (0.5901427 + 2*(1 - 0.5901427)*0.3 + 2 / 0.6613717*(706 / 689.55)^2*0.31 - (1.1895501^2 - 1) / (1.0*0.6613717) - (1 - 1.0)*[0^2 - 706^2] / (2*1.0*0.6613717*689.55^2))*0 =$	0
	Load case 2, 3, 6, 7	$P_s' = (0.5901427 + 2*(1 - 0.5901427)*0.3 + 2 / 0.6613717*(706 / 689.55)^2*0.31 - (1.1895501^2 - 1) / (1.0*0.6613717) - (1 - 1.0)*[0^2 - 706^2] / (2*1.0*0.6613717*689.55^2))*7{,}700.01 =$	9,172.53
New	Load case 1, 3, 5, 7	$P_t' = (0.7938642 + 2*(1 - 0.7938642)*0.3 + 1 / (1.0*0.7484617))*7{,}700.01 =$	17,352.9
	Load case 2, 6, 8	$P_t' = (0.7938642 + 2*(1 - 0.7938642)*0.3 + 1 / (1.0*0.7484617))*0 =$	0
Corroded	Load case 1, 3, 5, 7	$P_t' = (0.7938642 + 2*(1 - 0.7938642)*0.3 + 1 / (1.0*0.6613717))*7{,}700.01 =$	18,707.6
	Load case 2, 6, 8	$P_t' = (0.7938642 + 2*(1 - 0.7938642)*0.3 + 1 / (1.0*0.6613717))*0 =$	0
New or corroded	Load case 1, 2, 3	$P_\gamma = 537*2{,}399.01*0.0 / (\pi*344.78^2)*1000 =$	0
	Load case 5, 6, 7, 8	$P_\gamma = 537*2{,}399.01*5.2324357 / (\pi*344.78^2)*1000 =$	18,050.49
New or corroded	All load cases	$P_W = - 1.3368913*0*4{,}825{,}175.49 / (2*\pi*344.78^2)*1000 =$	0
New	Load case 1, 5	$P_{rim} = - 1.1715804 / 344.78^2*(2{,}337.8385994*0 - 2{,}337.8385994*7{,}700.01) =$	177.42
	Load case 2, 6	$P_{rim} = - 1.1715804 / 344.78^2*(2{,}337.8385994*7{,}700.01 - 2{,}337.8385994*0) =$	-177.42
	Load case 3, 7, 8	$P_{rim} = - 1.1715804 / 344.78^2*(2{,}337.8385994*7{,}700.01 - 2{,}337.8385994*7{,}700.01) =$	0
Corroded	Load case 1, 5	$P_{rim} = - 1.3368913 / 344.78^2*(2{,}337.8385994*0 - 2{,}337.8385994*7{,}700.01) =$	202.46
	Load case 2, 6	$P_{rim} = - 1.3368913 / 344.78^2*(2{,}337.8385994*7{,}700.01 - 2{,}337.8385994*0) =$	-202.46
	Load case 3, 7, 8	$P_{rim} = - 1.3368913 / 344.78^2*(2{,}337.8385994*7{,}700.01 - 2{,}337.8385994*7{,}700.01) =$	0
	Load case 1		-6,555.3

New

		P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1729811 + (1.1895501 - 1)*0.5857902])*(0 - 17,352.9 + 0 + 0 + 177.4216) =	
	Load case 2	P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1729811 + (1.1895501 - 1)*0.5857902])*(8,741.1364 - 0 + 0 + 0 + -177.4216) =	3,268.48
	Load case 3	P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1729811 + (1.1895501 - 1)*0.5857902])*(8,741.1364 - 17,352.9 + 0 + 0 + 0) =	-3,286.82
	Load case 5	P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1729811 + (1.1895501 - 1)*0.5857902])*(0 - 17,352.9 + 18,050.49 + 0 + 177.4216) =	333.96
	Load case 6	P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1729811 + (1.1895501 - 1)*0.5857902])*(8,741.1364 - 0 + 18,050.49 + 0 + -177.4216) =	10,157.74
	Load case 7	P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1729811 + (1.1895501 - 1)*0.5857902])*(8,741.1364 - 17,352.9 + 18,050.49 + 0 + 0) =	3,602.44
	Load case 8	P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1729811 + (1.1895501 - 1)*0.5857902])*(0 - 0 + 18,050.49 + 0 + 0) =	6,889.26
Corroded	Load case 1	P_e = 1.0*0.6613717 / (1 + 1.0*0.6613717*[1.1970316 + (1.1895501 - 1)*0.6684457])*(0 - 18,707.6 + 0 + 0 + 202.456) =	-6,525.68
	Load case 2	P_e = 1.0*0.6613717 / (1 + 1.0*0.6613717*[1.1970316 + (1.1895501 - 1)*0.6684457])*(9,172.5299 - 0 + 0 + 0 + -202.456) =	3,163.22
	Load case 3	P_e = 1.0*0.6613717 / (1 + 1.0*0.6613717*[1.1970316 + (1.1895501 - 1)*0.6684457])*(9,172.5299 - 18,707.6 + 0 + 0 + 0) =	-3,362.46
	Load case 5	P_e = 1.0*0.6613717 / (1 + 1.0*0.6613717*[1.1970316 + (1.1895501 - 1)*0.6684457])*(0 - 18,707.6 + 18,050.49 + 0 + 202.456) =	-160.33
	Load case 6	P_e = 1.0*0.6613717 / (1 + 1.0*0.6613717*[1.1970316 + (1.1895501 - 1)*0.6684457])*(9,172.5299 - 0 + 18,050.49 + 0 + -202.456) =	9,528.56
	Load case 7	P_e = 1.0*0.6613717 / (1 + 1.0*0.6613717*[1.1970316 + (1.1895501 - 1)*0.6684457])*(9,172.5299 - 18,707.6 + 18,050.49 + 0 + 0) =	3,002.89
	Load case 8	P_e = 1.0*0.6613717 / (1 + 1.0*0.6613717*[1.1970316 + (1.1895501 - 1)*0.6684457])*(0 - 0 + 18,050.49 + 0 + 0) =	6,365.35

UHX-13.5.7 Step 7

$Q_2 = ((\omega_s^{*}*P_s - \omega_c^{*}*P_t) + \gamma_b*W^{*} / (2*\pi)) / (1 + \Phi*Z_m)$

$Q_3 = Q_1 + 2*Q_2 / (P_e*a_o^2)$

F_m is calculated per Table UHX-13.1

$\sigma = (1.5*F_m / \mu^{*})*(2*a_o / (h - h_g'))^2*P_e$

If $P_e = 0$, $\sigma = 6*Q_2 / (\mu^{*}*(h - h_g')^2)$

Condition Operating

New	Load case 1, 5	Q_2 = ((2,337.8385994*0 - 2,337.8385994*7,700.01) / 1000 + 0*4,825,175.49 / (2*π)) / (1 + 0.7166051*0.7264957) =	-11,838.27
	Load case 2, 6	Q_2 = ((2,337.8385994*7,700.01 - 2,337.8385994*0) / 1000 + 0*4,825,175.49 / (2*π)) / (1 + 0.7166051*0.7264957) =	11,838.27
	Load case 3, 7, 8	Q_2 = ((2,337.8385994*7,700.01 - 2,337.8385994*7,700.01) / 1000 + 0*4,825,175.49 / (2*π)) / (1 + 0.7166051*0.7264957) =	0.0
Corroded	Load case 1, 5	Q_2 = ((2,337.8385994*0 - 2,337.8385994*7,700.01) / 1000 + 0*4,825,175.49 / (2*π)) / (1 + 0.7118338*0.7224302) =	-11,887.99
	Load case 2, 6	Q_2 = ((2,337.8385994*7,700.01 - 2,337.8385994*0) / 1000 + 0*4,825,175.49 / (2*π)) / (1 + 0.7118338*0.7224302) =	11,887.99
	Load case 3, 7, 8	Q_2 = ((2,337.8385994*7,700.01 - 2,337.8385994*7,700.01) / 1000 + 0*4,825,175.49 / (2*π)) / (1 + 0.7118338*0.7224302) =	0.0
New	Load case 1	Q_3 = 0.0402843 + 2*-11,838.27 / (-6,555.2974*344.78^2 / 1000) =	0.0706689
	Load case 2	Q_3 = 0.0402843 + 2*11,838.27 / (3,268.4793*344.78^2 / 1000) =	0.101224
	Load case 3, 7, 8	Q_3 = 0.0402843 + 2*0.0 / (-3,286.8181*344.78^2 / 1000) =	0.0402843
	Load case 5	Q_3 = 0.0402843 + 2*-11,838.27 / (333.964*344.78^2 / 1000) =	-0.5561284
	Load case 6	Q_3 = 0.0402843 + 2*11,838.27 / (10,157.74*344.78^2 / 1000) =	0.059893
Corroded	Load case 1	Q_3 = 0.0416583 + 2*-11,887.99 / (-6,525.6752*344.78^2 / 1000) =	0.0723091
	Load case 2	Q_3 = 0.0416583 + 2*11,887.99 / (3,163.2164*344.78^2 / 1000) =	0.1048905
	Load case 3, 7, 8	Q_3 = 0.0416583 + 2*0.0 / (-3,362.4588*344.78^2 / 1000) =	0.0416583
	Load case 5	Q_3 = 0.0416583 + 2*-11,887.99 / (-160.3295*344.78^2 / 1000) =	1.2891949
	Load case 6	Q_3 = 0.0416583 + 2*11,887.99 / (9,528.5621*344.78^2 / 1000) =	0.0626496

Tubesheet Bending Stress			Stress (MPa)	Allowable (MPa)	Over-stressed?
New	Load case 1	σ = (1.5*0.2229899 / 0.3741085)*(2*344.78 / (130 - 0))^2*-6,555.2974 / 1000 =	-164.898	207	No
	Load case 2	σ = (1.5*0.2367984 / 0.3741085)*(2*344.78 / (130 - 0))^2*3,268.4793 / 1000 =	87.31	207	No
	Load case 3	σ = (1.5*0.2092585 / 0.3741085)*(2*344.78 / (130 - 0))^2*-3,286.8181 / 1000 =	-77.588	207	No
	Load case 5	σ = (1.5*0.2780642 / 0.3741085)*(2*344.78 / (130 - 0))^2*333.964 / 1000 =	10.476	460	No
	Load case 6	σ = (1.5*0.2181201 / 0.3741085)*(2*344.78 / (130 - 0))^2*10,157.74 / 1000 =	249.937	460	No
	Load case 7	σ = (1.5*0.2092585 / 0.3741085)*(2*344.78 / (130 - 0))^2*3,602.4433 / 1000 =	85.039	460	No
	Load case 8	σ = (1.5*0.2092585 / 0.3741085)*(2*344.78 / (130 - 0))^2*6,889.2613 / 1000 =	162.628	460	No

Corroded	Load case 1	σ = (1.5*0.2210651 / 0.3765819)*(2*344.78 / (124 - 0))^2*-6,525.6752 / 1000 =	-177.69	207	No
	Load case 2	σ = (1.5*0.2355804 / 0.3765819)*(2*344.78 / (124 - 0))^2*3,163.2164 / 1000 =	91.788	207	No
	Load case 3	σ = (1.5*0.2074099 / 0.3765819)*(2*344.78 / (124 - 0))^2*-3,362.4588 / 1000 =	-85.902	207	No
	Load case 5	σ = (1.5*0.7631995 / 0.3765819)*(2*344.78 / (124 - 0))^2*-160.3295 / 1000 =	-15.072	460	No
	Load case 6	σ = (1.5*0.2167617 / 0.3765819)*(2*344.78 / (124 - 0))^2*9,528.5621 / 1000 =	254.406	460	No
	Load case 7	σ = (1.5*0.2074099 / 0.3765819)*(2*344.78 / (124 - 0))^2*3,002.8868 / 1000 =	76.716	460	No
	Load case 8	σ = (1.5*0.2074099 / 0.3765819)*(2*344.78 / (124 - 0))^2*6,365.3457 / 1000 =	162.618	460	No

UHX-13.5.8 Step 8				
$\tau = (1 / (4*\mu))*(1 / h)*\{4*A_p / C_p\}*ABS(P_e)$			for $abs(P_e) > 1.6*S*\mu*h / a_o$	
Condition Operating				
				Shear Calc Required
New	Load case 1	abs(-6,555.2974 / 1000) ≤ 1.6*138*0.25*130 / 344.78 =	20.811	No
	Load case 2	abs(3,268.4793 / 1000) ≤ 1.6*138*0.25*130 / 344.78 =	20.811	No
	Load case 3	abs(-3,286.8181 / 1000) ≤ 1.6*138*0.25*130 / 344.78 =	20.811	No
	Load case 5	abs(333.964 / 1000) ≤ 1.6*138*0.25*130 / 344.78 =	20.811	No
	Load case 6	abs(10,157.74 / 1000) ≤ 1.6*138*0.25*130 / 344.78 =	20.811	No
	Load case 7	abs(3,602.4433 / 1000) ≤ 1.6*138*0.25*130 / 344.78 =	20.811	No
	Load case 8	abs(6,889.2613 / 1000) ≤ 1.6*138*0.25*130 / 344.78 =	20.811	No
Corroded	Load case 1	abs(-6,525.6752 / 1000) ≤ 1.6*138*0.25*124 / 344.78 =	19.851	No
	Load case 2	abs(3,163.2164 / 1000) ≤ 1.6*138*0.25*124 / 344.78 =	19.851	No
	Load case 3	abs(-3,362.4588 / 1000) ≤ 1.6*138*0.25*124 / 344.78 =	19.851	No
	Load case 5	abs(-160.3295 / 1000) ≤ 1.6*138*0.25*124 / 344.78 =	19.851	No
	Load case 6	abs(9,528.5621 / 1000) ≤ 1.6*138*0.25*124 / 344.78	19.851	No

		=		
	Load case 7	abs(3,002.8868 / 1000) ≤ 1.6*138*0.25*124 / 344.78 =	19.851	No
	Load case 8	abs(6,365.3457 / 1000) ≤ 1.6*138*0.25*124 / 344.78 =	19.851	No

UHX-13.5.9 Step 9			
$F_t(x) = [Z_d(x) + Q_3*Z_w(x)]*X_a^4 / 2$			
If $P_e = 0$, $F_t(x) = Z_w(x)*X_a^4 / 2$			
$F_{t,min} = Min[F_t(x)]$			
$F_{t,max} = Max[F_t(x)]$			
$F_s = MAX [(3.25 - 0.25*(Z_d + Q_3*Z_w)*X_a^4), 1.25]$ but not greater than 2			
If $P_e = 0$, $F_s = 1.25$			
$\sigma_{t,1} = 1 / (x_t - x_s)*[(P_s*x_s - P_t*x_t) - P_e*F_{t,min}]$			
$\sigma_{t,2} = 1 / (x_t - x_s)*[(P_s*x_s - P_t*x_t) - P_e*F_{t,max}]$			
If $P_e = 0$, $\sigma_{t,1} = 1 / (x_t - x_s)*[(P_s*x_s - P_t*x_t) - (2*Q_2 / a_o^2)*F_{t,min}]$			
If $P_e = 0$, $\sigma_{t,2} = 1 / (x_t - x_s)*[(P_s*x_s - P_t*x_t) - (2*Q_2 / a_o^2)*F_{t,max}]$			
$I_t = k*I$			
$r_t = (d_t^2 + (d_t - 2*t_t)^2)^{0.5} / 4$			
$F_t = I_t / r_t$			
$C_t = (2*\pi^2*E_t / S_{y,t})^{0.5}$			
For $C_t \leq F_t$, $S_{tb} = Min\{\pi^2*E_t / (F_s*F_t^2), S_t\}$			
For $C_t > F_t$, $S_{tb} = Min\{S_{y,t} / F_s*(1 - F_t / (2*C_t)), S_t\}$			
$\sigma_{t,min} = MIN[\sigma_{t,1}, \sigma_{t,2}]$			
Condition Operating			
New	Load case 1	$F_{t,min}$ = [0.2920741 + 0.0706689*-0.1755448]*1.5400077 ^{4} / 2 =	0.7865
	Load case 2	$F_{t,min}$ = [0.2920741 + 0.101224*-0.1755448]*1.5400077 ^{4} / 2 =	0.7714
	Load case 3, 7, 8	$F_{t,min}$ = [0.2920741 + 0.0402843*-0.1755448]*1.5400077 ^{4} / 2 =	0.8015
	Load case 5	$F_{t,min}$ = [0.4098776 + -0.5561284*0.1790294]*1.5400077 ^{4} / 2 =	0.8727
	Load case 6	$F_{t,min}$ = [0.2920741 + 0.059893*-0.1755448]*1.5400077 ^{4} / 2 =	0.7918
Corroded	Load case 1	$F_{t,min}$ = [0.2479232 + 0.0723091*-0.1737228]*1.5926952 ^{4} / 2 =	0.7572
	Load case 2	$F_{t,min}$ = [0.2479232 + 0.1048905*-0.1737228]*1.5926952 ^{4} / 2 =	0.739
	Load case 3, 7, 8	$F_{t,min}$ = [0.2479232 + 0.0416583*-0.1737228]*1.5926952 ^{4} / 2 =	0.7744
	Load case 5	$F_{t,min}$ = [0.2479232 + 1.2891949*-0.1737228]*1.5926952 ^{4} / 2 =	0.0771
	Load case 6	$F_{t,min}$ = [0.2479232 + 0.0626496*-0.1737228]*1.5926952 ^{4} / 2 =	0.7626
New	Load case 1	$F_{t,max}$ = [0.4098776 + 0.0706689*0.1790294]*1.5400077 ^{4} / 2 =	1.1883
	Load case 2	$F_{t,max}$ = [0.4098776 + 0.101224*0.1790294]*1.5400077 ^{4} / 2 =	1.2037

	Load case 3, 7, 8	$F_{t,max}$ = [0.4098776 + 0.0402843*0.1790294]*1.5400077 ^4 / 2 =	1.173
	Load case 5	$F_{t,max}$ = [0.2920741 + -0.5561284*-0.1755448]*1.5400077 ^4 / 2 =	1.096
	Load case 6	$F_{t,max}$ = [0.4098776 + 0.059893*0.1790294]*1.5400077 ^4 / 2 =	1.1829
Corroded	Load case 1	$F_{t,max}$ = [0.3646518 + 0.0723091*0.1776664]*1.5926952 ^4 / 2 =	1.2146
	Load case 2	$F_{t,max}$ = [0.3646518 + 0.1048905*0.1776664]*1.5926952 ^4 / 2 =	1.2332
	Load case 3, 7, 8	$F_{t,max}$ = [0.3646518 + 0.0416583*0.1776664]*1.5926952 ^4 / 2 =	1.197
	Load case 5	$F_{t,max}$ = [0.3646518 + 1.2891949*0.1776664]*1.5926952 ^4 / 2 =	1.9101
	Load case 6	$F_{t,max}$ = [0.3646518 + 0.0626496*0.1776664]*1.5926952 ^4 / 2 =	1.209
New	Load case 1	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 7,700.01*0.7938642) - -6,555.2974*0.7865] =	-4.697
	Load case 2	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 0*0.7938642) - 3,268.4793*0.7714] =	9.929
	Load case 3	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 7,700.01*0.7938642) - -3,286.8181*0.8015] =	5.231
	Load case 5	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 7,700.01*0.7938642) - 333.964*0.8727] =	-31.436
	Load case 6	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 0*0.7938642) - 10,157.74*0.7918] =	-17.176
	Load case 7	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 7,700.01*0.7938642) - 3,602.4433*0.8015] =	-21.873
	Load case 8	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 0*0.7938642) - 6,889.2613*0.8015] =	-27.105
Corroded	Load case 1	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 7,700.01*0.7938642) - -6,525.6752*0.7572] =	-5.749
	Load case 2	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 0*0.7938642) - 3,163.2164*0.739] =	10.83
	Load case 3	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 7,700.01*0.7938642) - -3,362.4588*0.7744] =	5.081
	Load case 5	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 7,700.01*0.7938642) - -160.3295*0.0771] =	-29.945
	Load case 6	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 0*0.7938642) - 9,528.5621*0.7626] =	-13.365
	Load case 7	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 7,700.01*0.7938642) - 3,002.8868*0.7744] =	-19.114
	Load case 8	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 0*0.7938642) - 6,365.3457*0.7744] =	-24.196
New	Load case 1	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 7,700.01*0.7938642) - -6,555.2974*1.1883] =	8.231
	Load case 2	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 0*0.7938642) - 3,268.4793*1.2037] =	2.994
	Load case 3	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 7,700.01*0.7938642) - -3,286.8181*1.173] =	11.225
	Load case 5	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 7,700.01*0.7938642) - 333.964*1.096] =	-31.802
	Load case 6	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 0*0.7938642) - 10,157.74*1.1829] =	-36.673
	Load case 7	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 7,700.01*0.7938642) - 3,602.4433*1.173] =	-28.442
	Load case 8	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 0*0.7938642) - 6,889.2613*1.173] =	-39.667
Corroded	Load case 1	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 7,700.01*0.7938642) - -6,525.6752*1.2146] =	8.899
	Load case 2	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 0*0.7938642) - 3,163.2164*1.2332] =	3.158

	Load case 3	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 7,700.01*0.7938642) - -3,362.4588*1.197] =			12.057
	Load case 5	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 7,700.01*0.7938642) - -160.3295*1.9101] =			-28.502
	Load case 6	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 0*0.7938642) - 9,528.5621*1.209] =			-34.244
	Load case 7	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(7,700.01*0.5901427 - 7,700.01*0.7938642) - 3,002.8868*1.197] =			-25.344
	Load case 8	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 0*0.7938642) - 6,365.3457*1.197] =			-37.402
New or corroded	All load cases	r_t = (19.05^2 + (19.05 - 2*2.77)^2)$^{0.5}$ / 4 =			5.84
New	All load cases	F_t = 626.4 / 5.84 =			107.2865
Corroded	All load cases	F_t = 624 / 5.84 =			106.8755
New or corroded	Load case 1, 5, 6, 7, 8	C_t = (2*π^2*198,800.004 / 165)$^{0.5}$ =			154.2166
	Load case 2, 3	C_t =			0
New or corroded	All load cases	F_s = MAX [(3.25 - 0.25*(0.4098776 + 0.0706689*0.1790294)*1.5400077 ^{4}), 1.25] but not greater than 2 =			2
New	Load case 1, 5, 6, 7, 8	S_{tb} = Min{165 / 2*(1 - 107.2865 / (2*154.2166)) = 53.803, 92.4} =			53.803
	Load case 2, 3	S_{tb} =			N/A
Corroded	Load case 1, 5, 6, 7, 8	S_{tb} = Min{165 / 2*(1 - 106.8755 / (2*154.2166)) = 53.913, 92.4} =			53.913
	Load case 2, 3	S_{tb} =			N/A
Tube Evaluation			**Stress (MPa)**	**Allowable (MPa)**	**Over-stressed?**
New	Load case 1	$\sigma_{t,max}$ = MAX[ABS(-4.697), ABS(8.231)] =	8.231	92.4	No
	Load case 2	$\sigma_{t,max}$ = MAX[ABS(9.929), ABS(2.994)] =	9.929	92.4	No
	Load case 3	$\sigma_{t,max}$ = MAX[ABS(5.231), ABS(11.225)] =	11.225	92.4	No
	Load case 5	$\sigma_{t,max}$ = MAX[ABS(-31.436), ABS(-31.802)] =	31.802	184.8	No
	Load case 6	$\sigma_{t,max}$ = MAX[ABS(-17.176), ABS(-36.673)] =	36.673	184.8	No
	Load case 7	$\sigma_{t,max}$ = MAX[ABS(-21.873), ABS(-28.442)] =	28.442	184.8	No
	Load case 8	$\sigma_{t,max}$ = MAX[ABS(-27.105), ABS(-39.667)] =	39.667	184.8	No
Corroded	Load case 1	$\sigma_{t,max}$ = MAX[ABS(-5.749), ABS(8.899)] =	8.899	92.4	No
	Load case 2	$\sigma_{t,max}$ = MAX[ABS(10.83), ABS(3.158)] =	10.83	92.4	No
	Load case 3	$\sigma_{t,max}$ = MAX[ABS(5.081), ABS(12.057)] =	12.057	92.4	No
	Load case 5	$\sigma_{t,max}$ = MAX[ABS(-29.945), ABS(-28.502)] =	29.945	184.8	No
	Load case 6	$\sigma_{t,max}$ = MAX[ABS(-13.365), ABS(-34.244)] =	34.244	184.8	No
	Load case 7	$\sigma_{t,max}$ = MAX[ABS(-19.114), ABS(-25.344)] =	25.344	184.8	No
	Load case 8	$\sigma_{t,max}$ = MAX[ABS(-24.196), ABS(-37.402)] =	37.402	184.8	No
New	Load case 1	$\sigma_{t,min}$ = MIN[-4.697, 8.231] =	-4.697	53.803	No
	Load case 2	$\sigma_{t,min}$ = MIN[9.929, 2.994] =	2.994	N/A	No
	Load case 3	$\sigma_{t,min}$ = MIN[5.231, 11.225] =	5.231	N/A	No
	Load case 5	$\sigma_{t,min}$ = MIN[-31.436, -31.802] =	-31.802	53.803	No
	Load case 6	$\sigma_{t,min}$ = MIN[-17.176, -36.673] =	-36.673	53.803	No

	Load case 7	$\sigma_{t,min}$ = MIN[-21.873, -28.442] =	-28.442	53.803	No
	Load case 8	$\sigma_{t,min}$ = MIN[-27.105, -39.667] =	-39.667	53.803	No
Corroded	Load case 1	$\sigma_{t,min}$ = MIN[-5.749, 8.899] =	-5.749	53.913	No
	Load case 2	$\sigma_{t,min}$ = MIN[10.83, 3.158] =	3.158	N/A	No
	Load case 3	$\sigma_{t,min}$ = MIN[5.081, 12.057] =	5.081	N/A	No
	Load case 5	$\sigma_{t,min}$ = MIN[-29.945, -28.502] =	-29.945	53.913	No
	Load case 6	$\sigma_{t,min}$ = MIN[-13.365, -34.244] =	-34.244	53.913	No
	Load case 7	$\sigma_{t,min}$ = MIN[-19.114, -25.344] =	-25.344	53.913	No
	Load case 8	$\sigma_{t,min}$ = MIN[-24.196, -37.402] =	-37.402	53.913	No

UHX-13.5.10 Step 10							
$\sigma_{s,m} = a_o^2 / (t_s*(D_s + t_s))*[P_e + (\rho_s^2 - 1)*(P_s - P_t)] + a_s^2*P_t / (t_s*(D_s + t_s))$							
Condition Operating							
Shell Evaluation			Stress (MPa)	$S_s*E_{s,w}$ (MPa)	$S_{PS,s}$ (MPa)	$S_{s,b}$ (MPa)	Over-stressed?
New	Load case 1	$\sigma_{s,m}$ = 344.78² / (25*(700 + 25)) / 1000*[-6,555.2974 + (1.1895501² - 1)*(0 - 7,700.01)] + 410.13²*7,700.01 / (25*(700 + 25)) / 1000 =	7.507	138	N/A	N/A	No
	Load case 2	$\sigma_{s,m}$ = 344.78² / (25*(700 + 25)) / 1000*[3,268.4793 + (1.1895501² - 1)*(7,700.01 - 0)] + 410.13²*0 / (25*(700 + 25)) / 1000 =	42.394	138	N/A	N/A	No
	Load case 3	$\sigma_{s,m}$ = 344.78² / (25*(700 + 25)) / 1000*[-3,286.8181 + (1.1895501² - 1)*(7,700.01 - 7,700.01)] + 410.13²*7,700.01 / (25*(700 + 25)) / 1000 =	49.902	138	N/A	N/A	No
	Load case 5	$\sigma_{s,m}$ = 344.78² / (25*(700 + 25)) / 1000*[333.964 + (1.1895501² - 1)*(0 - 7,700.01)] + 410.13²*7,700.01 / (25*(700 + 25)) / 1000 =	52.69	N/A	484	N/A	No
	Load case 6	$\sigma_{s,m}$ = 344.78² / (25*(700 + 25)) / 1000*[10,157.74 + (1.1895501² - 1)*(7,700.01 - 0)] + 410.13²*0 / (25*(700 + 25)) / 1000 =	87.577	N/A	484	N/A	No
	Load case 7	$\sigma_{s,m}$ = 344.78² / (25*(700 + 25)) / 1000*[3,602.4433 + (1.1895501² - 1)*(7,700.01 - 7,700.01)] + 410.13²*7,700.01 / (25*(700 + 25)) / 1000 =	95.084	N/A	484	N/A	No
	Load case 8	$\sigma_{s,m}$ = 344.78² / (25*(700 + 25)) / 1000*[6,889.2613 + (1.1895501² - 1)*(0 - 0)] + 410.13²*0 / (25*(700 + 25)) / 1000 =	45.182	N/A	484	N/A	No
Corroded	Load case 1	$\sigma_{s,m}$ = 344.78² / (22*(706 + 22)) / 1000*[-6,525.6752 + (1.1895501² - 1)*(0 - 7,700.01)] + 410.13²*7,700.01 / (22*(706 + 22)) / 1000 =	8.716	138	N/A	N/A	No
	Load case 2	$\sigma_{s,m}$ = 344.78² / (22*(706 + 22)) / 1000*[3,163.2164 + (1.1895501² - 1)*(7,700.01 - 0)] + 410.13²*0 / (22*(706 + 22)) / 1000 =	47.196	138	N/A	N/A	No
	Load case 3	$\sigma_{s,m}$ = 344.78² / (22*(706 + 22)) / 1000*[-3,362.4588 + (1.1895501² - 1)*(7,700.01 - 7,700.01)] + 410.13²*7,700.01 / (22*(706 + 22)) / 1000 =	55.912	138	N/A	N/A	No
	Load case 5	$\sigma_{s,m}$ = 344.78² / (22*(706 + 22)) / 1000*[-160.3295 + (1.1895501² - 1)*(0 - 7,700.01)] + 410.13²*7,700.01 / (22*(706 + 22)) / 1000 =	55.959	N/A	484	N/A	No
	Load case 6	$\sigma_{s,m}$ = 344.78² / (22*(706 + 22)) / 1000*[9,528.5621 + (1.1895501² - 1)*(7,700.01 - 0)] + 410.13²*0 / (22*(706 + 22)) / 1000 =	94.439	N/A	484	N/A	No
	Load case 7	$\sigma_{s,m}$ = 344.78² / (22*(706 + 22)) / 1000*[3,002.8868 + (1.1895501² - 1)*(7,700.01 - 7,700.01)] + 410.13²*7,700.01 / (22*(706 + 22)) / 1000 =	103.155	N/A	484	N/A	No
	Load case 8	$\sigma_{s,m}$ = 344.78² / (22*(706 + 22)) / 1000*[6,365.3457 + (1.1895501² - 1)*(0 - 0)] + 410.13²*0 / (22*(706 + 22)) / 1000 =	47.243	N/A	484	N/A	No

Calculations for Tube side hydrotest Condition

UHX-9.5			
$h_r = D_E / (3.2*S)*abs(P_s - P_t)$			
Condition Tube side hydrotest			
New	Load case 1	h_r = 807 / (3.2*223.2)*abs(0 - 10,314.63) =	11.65
Tubesheet Design Thickness to Maintain h_r = 11.65 + 11.2 + 11.2 = 34.05 mm			

UHX-13.5.1 Step 1		
Condition Tube side hydrotest		
New	D_o = 2*335.25 + 19.05 =	689.55
New	μ = (25.4 - 19.05) / 25.4 =	0.25
New	d^* = MAX{[19.05 - 2*2.77*(201,999.998 / 201,999.998)*(161.1 / 223.2)*0.85], [19.05 - 2*2.77]} =	15.6511653
New	p^* = 25.4 / (1 - 4*MIN(0, 4*689.55*25.4) / (π*689.55^2))$^{0.5}$ =	25.4
New	μ^* = (25.399 - 15.6511653) / 25.399 =	0.383788
	h_g' =	0
New	a_o = 689.55 / 2 =	344.78
New	ρ_s = 410.13 / 344.78 =	1.18955
New	ρ_c = 410.13 / 344.78 =	1.18955
New	x_s = 1 - 537*(19.05 / (2*344.78))^2 =	0.590143
New	x_t = 1 - 537*((19.05 - 2*2.77) / (2*344.78))^2 =	0.793864

UHX-13.5.2 Step 2		
Condition Tube side hydrotest		
New	K_s = π*25*(700 + 25)*201,999.998 / 11,740 =	979,740.56
New	K_t = π*2.77*(19.05 - 2.77)*201,999.998 / 11,740 =	2,437.63
New	$K_{s,t}$ = 979,740.56 / (537*2,437.63) =	0.748462
New	J = 1 as no expansion joint used	

UHX-13.5.3 Step 3		
Condition Tube side hydrotest		
New	h / p = 130 / 25.4 =	5.1183
New	- from Fig. UHX-11.4(a) E^* / E =	0.4393
New	E^* = 0.439279*201,999.998 =	88,734.351
New	- from Fig. UHX-11.4(b) ν^* =	0.3181
New	X_a = [24*(1 - 0.3181039^2)*537*201,999.998*2.77*(19.05 - 2.77)*344.78^2 / (88,734.351*11,740*130^3)]$^{0.25}$ =	1.53
New	Z_d =	0.4193465
New	Z_v =	0.1794267
New	Z_m =	0.7278439
New	Z_w =	0.1794267
New	Z_a =	0.5405854

UHX-13.5.4 Step 4		
Condition Tube side hydrotest		
New	K = 970 / 689.55 =	1.4067145
New	F = ((1 - 0.3181039) / 88,734.351)*(0 + 0 + 201,999,998.16*ln(1.4067)) / 1000 =	0.5297356
New	Φ = (1 + 0.3181039)*0.5297356 =	0.6982466
New	Q_1 = (1.1895501 - 1 - 0.6982466*0.1794267) / (1 + 0.6982466*0.7278439) =	0.0426107
New	Q_{z1} = (0.4193465 + 0.0426107*0.1794267)*1.5300483^4 / 2 =	1.1701
New	Q_{z2} = (0.1794267 + 0.0426107*0.7278439)*1.5300483^4 / 2 =	0.5767
New	U = [0.1794267 + (1.1895501 - 1)*0.7278439]*1.5300483^4 / (1 +0.6982466*0.7278439) =	1.1533

UHX-13.5.5 Step 5		
Condition Tube side hydrotest		
New	γ_b = (820.25 - 820.25) / 689.55 =	0

UHX-13.5.5 Step 5			
Condition Tube side hydrotest			
		P_s (kPa)	P_t (kPa)
Load Case 1		0	10,314.63
New	Load case 1	γ =	0
New	Load case 1	ω_s = 1.1895501*0.0*0.0*0*(1 + 130*0.0) =	0
New	Load case 1	ω_s^* = 344.78^2*(1.1895501^2 - 1)*(1.1895501 - 1) / 4 - 0.0 =	2,337.8386
New	Load case 1	ω_c = 1.1895501*0.0*0.0*0*(1 + 130*0.0) =	0
New	Load case 1	ω_c^* = 344.78^2*[(1.1895501^2 + 1)*(1.1895501 - 1) / 4 - (1.1895501 - 1) / 2] - 0.0 =	2,337.8386

UHX-13.5.6 Step 6			
Condition Tube side hydrotest			
New	Load case 1	P_s' = (0.5901427 + 2*(1 - 0.5901427)*0.3 + 2 / 0.7484617*(700 / 689.55)^2*0.31 - (1.1895501^2 - 1) / (1.0*0.7484617) - (1 - 1.0)*[0^2 - 700^2] / (2*1.0*0.7484617*689.55^2))*0 =	0
New	Load case 1	P_t' = (0.7938642 + 2*(1 - 0.7938642)*0.3 + 1 / (1.0*0.7484617))*10,314.63 =	23,245.26
New	Load case 1	P_γ = 537*2,437.63*0.0 / (π*344.78^2)*1000 =	0
New	Load case 1	P_W = - 1.1533206*0*6,463,614.18 / (2*π*344.78^2)*1000 =	0
New	Load case 1	P_{rim} = - 1.1533206 / 344.78^2*(2,337.8385994*0 - 2,337.8385994*10,314.63) =	233.96
New	Load case 1	P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1700657 + (1.1895501 - 1)*0.5766603])*(0 - 23,245.26 + 0 + 0 + 233.9628) =	-8,798.23

UHX-13.5.7 Step 7					
Condition Tube side hydrotest					
New	Load case 1	Q_2 = ((2,337.8385994*0 - 2,337.8385994*10,314.63) / 1000 + 0*6,463,614.18 / (2*π)) / (1 + 0.6982466*0.7278439) =			-15,988.41
New	Load case 1	Q_3 = 0.0426107 + 2*-15,988.41 / (-8,798.232*344.78^2 / 1000) =			0.0731858
Tubesheet Bending Stress			**Stress (MPa)**	**Allowable (MPa)**	**Over-stressed?**
New	Load case 1	σ = (1.5*0.2245321 / 0.3837881)*(2*344.78 / (130 - 0))^2*-8,798.232 / 1000 =	-217.229	334.8	No

UHX-13.5.8 Step 8				
Condition Tube side hydrotest				
				Shear Calc Required
New	Load case 1	abs(-8,798.232 / 1000) ≤ 1.6*223.2*0.25*130 / 344.78 =	33.66	No

UHX-13.5.9 Step 9					
Condition Tube side hydrotest					
New	Load case 1	$F_{t,min}$ = [0.3012754 + 0.0731858*-0.1760217]*1.5300483^{4} / 2 =			0.7903
New	Load case 1	$F_{t,max}$ = [0.4193465 + 0.0731858*0.1794267]*1.5300483^{4} / 2 =			1.1851
New	Load case 1	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 10,314.63*0.7938642) - -8,798.232*0.7903] =			-6.064
New	Load case 1	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(0*0.5901427 - 10,314.63*0.7938642) - -8,798.232*1.1851] =			10.987
New	Load case 1	r_t = (19.05^{2} + $(19.05 - 2*2.77)^{2}$ $)^{0.5}$ / 4 =			5.84
New	Load case 1	F_t = 626.4 / 5.84 =			107.2865
New	Load case 1	C_t = $(2*\pi^{2}*201,999.998 / 179)^{0.5}$ =			149.2499
New	Load case 1	F_s = MAX [(3.25 - 0.25*(0.4193465 + 0.0731858*0.1794267)*1.5300483^{4}), 1.25] but not greater than 2 =			2
New	Load case 1	S_{tb} = Min{179 / 2*(1 - 107.2865 / (2*149.2499)) = 57.332, 161.1} =			57.332
Tube Evaluation			Stress (MPa)	Allowable (MPa)	Over-stressed?
New	Load case 1	$\sigma_{t,max}$ = MAX[ABS(-6.064), ABS(10.987)] =	10.987	161.1	No
New	Load case 1	$\sigma_{t,min}$ = MIN[-6.064, 10.987] =	-6.064	57.332	No

UHX-13.5.10 Step 10							
Condition Tube side hydrotest							
Shell Evaluation			Stress (MPa)	$S_s*E_{s,w}$ (MPa)	$S_{PS,s}$ (MPa)	$S_{s,b}$ (MPa)	Over-stressed?
New	Load case 1	$\sigma_{s,m}$ = 344.78^{2} / (25*(700 + 25)) / 1000*[-8,798.232 + (1.1895501^{2} - 1)*(0 - 10,314.63)] + 410.13^{2}*10,314.63 / (25*(700 + 25)) / 1000 =	9.945	235.8	N/A	N/A	No

Calculations for Shell side hydrotest Condition

UHX-9.5			
$h_{r,operating} = (1.9*W_{m1}*h_G / (S*G))^{0.5}$			
$h_{r,gasket\ seating} = (1.9*W*h_G / (S_a*G))^{0.5}$			
$h_r = max[h_{r,gasket\ seating}, h_{r,operating}]$			
Condition Shell side hydrotest			
Operating			
New	Load case 2	$h_r = (1.9*6,491,822.21*35.87 / (223.2*820.25))^{0.5} =$	49.16
Gasket Seating			
New	Load case 2	$h_r = (1.9*6,491,822.21*35.87 / (223.2*820.25))^{0.5} =$	49.16
Tubesheet Design Thickness to Maintain h_r = 49.16 + 11.2 + 11.2 = 71.56 mm			

UHX-13.5.1 Step 1		
Condition Shell side hydrotest		
New	$D_o = 2*335.25 + 19.05 =$	689.55
New	$\mu = (25.4 - 19.05) / 25.4 =$	0.25
New	$d^* = MAX\{[19.05 - 2*2.77*(201,999.998 / 201,999.998)*(161.1 / 223.2)*0.85], [19.05 - 2*2.77]\} =$	15.6511653
New	$p^* = 25.4 / (1 - 4*MIN(0, 4*689.55*25.4) / (\pi*689.55^2))^{0.5} =$	25.4
New	$\mu^* = (25.399 - 15.6511653) / 25.399 =$	0.383788
	$h_g' =$	0
New	$a_o = 689.55 / 2 =$	344.78
New	$\rho_s = 410.13 / 344.78 =$	1.18955
New	$\rho_c = 410.13 / 344.78 =$	1.18955
New	$x_s = 1 - 537*(19.05 / (2*344.78))^2 =$	0.590143
New	$x_t = 1 - 537*((19.05 - 2*2.77) / (2*344.78))^2 =$	0.793864

UHX-13.5.2 Step 2		
Condition Shell side hydrotest		
New	$K_s = \pi*25*(700 + 25)*201,999.998 / 11,740 =$	979,740.56
New	$K_t = \pi*2.77*(19.05 - 2.77)*201,999.998 / 11,740 =$	2,437.63
New	$K_{s,t} = 979,740.56 / (537*2,437.63) =$	0.748462
New	J = 1 as no expansion joint used	

UHX-13.5.3 Step 3		
Condition Shell side hydrotest		
New	h / p = 130 / 25.4 =	5.1183
New	- from Fig. UHX-11.4(a) E^* / E =	0.4393
New	E^* = 0.439279*201,999.998 =	88,734.351
New	- from Fig. UHX-11.4(b) ν^* =	0.3181
New	$X_a = [24*(1 - 0.3181039^2)*537*201,999.998*2.77*(19.05 - 2.77)*344.78^2 / (88,734.351*11,740*130^3)]^{0.25}$ =	1.53
New	Z_d =	0.4193465
New	Z_v =	0.1794267
New	Z_m =	0.7278439
New	Z_w =	0.1794267
New	Z_a =	0.5405854

UHX-13.5.4 Step 4		
Condition Shell side hydrotest		
New	K = 970 / 689.55 =	1.4067145
New	F = ((1 - 0.3181039) / 88,734.351)*(0 + 0 + 201,999,998.16*ln(1.4067)) / 1000 =	0.5297356
New	Φ = (1 + 0.3181039)*0.5297356 =	0.6982466
New	Q_1 = (1.1895501 - 1 - 0.6982466*0.1794267) / (1 + 0.6982466*0.7278439) =	0.0426107
New	$Q_{z1} = (0.4193465 + 0.0426107*0.1794267)*1.5300483^4 / 2$ =	1.1701
New	$Q_{z2} = (0.1794267 + 0.0426107*0.7278439)*1.5300483^4 / 2$ =	0.5767
New	$U = [0.1794267 + (1.1895501 - 1)*0.7278439]*1.5300483^4 / (1 +0.6982466*0.7278439)$ =	1.1533

UHX-13.5.5 Step 5		
Condition Shell side hydrotest		
New	γ_b = (820.25 - 820.25) / 689.55 =	0

UHX-13.5.5 Step 5			
Condition Shell side hydrotest			
		P_s (kPa)	P_t (kPa)
Load Case 2		10,359.65	0
New	Load case 2	γ =	0
New	Load case 2	ω_s = 1.1895501*0.0*0.0*0*(1 + 130*0.0) =	0
New	Load case 2	ω_s^* = 344.78^2*(1.1895501^2 - 1)*(1.1895501 - 1) / 4 - 0.0 =	2,337.8386
New	Load case 2	ω_c = 1.1895501*0.0*0.0*0*(1 + 130*0.0) =	0
New	Load case 2	ω_c^* = 344.78^2*[(1.1895501^2 + 1)*(1.1895501 - 1) / 4 - (1.1895501 - 1) / 2] - 0.0 =	2,337.8386

UHX-13.5.6 Step 6			
Condition Shell side hydrotest			
New	Load case 2	P_s' = (0.5901427 + 2*(1 - 0.5901427)*0.3 + 2 / 0.7484617*(700 / 689.55)^2*0.31 - (1.1895501^2 - 1) / (1.0*0.7484617) - (1 - 1.0)*[0^2 - 700^2] / (2*1.0*0.7484617*689.55^2))*10,359.65 =	11,760.38
New	Load case 2	P_t' = (0.7938642 + 2*(1 - 0.7938642)*0.3 + 1 / (1.0*0.7484617))*0 =	0
New	Load case 2	P_γ = 537*2,437.63*0.0 / (π*344.78^2)*1000 =	0
New	Load case 2	P_W = - 1.1533206*0*6,491,822.21 / (2*π*344.78^2)*1000 =	0
New	Load case 2	P_{rim} = - 1.1533206 / 344.78^2*(2,337.8385994*10,359.65 - 2,337.8385994*0) =	-234.98
New	Load case 2	P_e = 1.0*0.7484617 / (1 + 1.0*0.7484617*[1.1700657 + (1.1895501 - 1)*0.5766603])*(11,760.38 - 0 + 0 + 0 + -234.9839) =	4,406.67

UHX-13.5.7 Step 7					
Condition Shell side hydrotest					
New	Load case 2	Q_2 = ((2,337.8385994*10,359.65 - 2,337.8385994*0) / 1000 + 0*6,491,822.21 / (2*π)) / (1 + 0.6982466*0.7278439) =			16,058.18
New	Load case 2	Q_3 = 0.0426107 + 2*16,058.18 / (4,406.6671*344.78^2 / 1000) =			0.1039226
Tubesheet Bending Stress			Stress (MPa)	Allowable (MPa)	Over-stressed?
New	Load case 2	σ = (1.5*0.2384575 / 0.3837881)*(2*344.78 / (130 - 0))^2*4,406.6671 / 1000 =	115.549	334.8	No

UHX-13.5.8 Step 8				
Condition Shell side hydrotest				
				Shear Calc Required
New	Load case 2	abs(4,406.6671 / 1000) ≤ 1.6*223.2*0.25*130 / 344.78 =	33.66	No

UHX-13.5.9 Step 9					
Condition Shell side hydrotest					
New	Load case 2	$F_{t,min}$ = [0.3012754 + 0.1039226*-0.1760217]*1.5300483 ^{4} / 2 =			0.7754
New	Load case 2	$F_{t,max}$ = [0.4193465 + 0.1039226*0.1794267]*1.5300483 ^{4} / 2 =			1.2002
New	Load case 2	$\sigma_{t,1}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(10,359.65*0.5901427 - 0*0.7938642) - 4,406.6671*0.7754] =			13.236
New	Load case 2	$\sigma_{t,2}$ = 1 / (0.7938642 - 0.5901427) / 1000*[(10,359.65*0.5901427 - 0*0.7938642) - 4,406.6671*1.2002] =			4.048
New	Load case 2	r_t = (19.05^2 + (19.05 - 2*2.77)^2)$^{0.5}$ / 4 =			5.84
New	Load case 2	F_t = 626.4 / 5.84 =			107.2865
New	Load case 2	C_t =			0
New	Load case 2	F_s = MAX [(3.25 - 0.25*(0.4193465 + 0.1039226*0.1794267)*1.5300483 ^{4}), 1.25] but not greater than 2 =			2
New	Load case 2	S_{tb} =			N/A
Tube Evaluation			Stress (MPa)	Allowable (MPa)	Over-stressed?
New	Load case 2	$\sigma_{t,max}$ = MAX[ABS(13.236), ABS(4.048)] =	13.236	161.1	No
New	Load case 2	$\sigma_{t,min}$ = MIN[13.236, 4.048] =	4.048	N/A	No

UHX-13.5.10 Step 10							
Condition Shell side hydrotest							
Shell Evaluation			Stress (MPa)	S_s*$E_{s,w}$ (MPa)	$S_{PS,s}$ (MPa)	$S_{s,b}$ (MPa)	Over-stressed?
New	Load case 2	$\sigma_{s,m}$ = 344.78^2 / (25*(700 + 25)) / 1000*[4,406.6671 + (1.1895501^2 - 1)*(10,359.65 - 0)] + 410.13^2*0 / (25*(700 + 25)) / 1000 =	57.098	235.8	N/A	N/A	No

Tube-To-Tubesheet Joint Loads

ASME Tube To Tubesheet Joint Loads - Periphery Of Bundle			
$W_j = \sigma_{t,o}*A_t$			
$L_{max} = A_t*S_a*f_e*f_r*f_y$			
Condition Operating			N
New	Load case 1	W_j = 8.231*141.672 =	1,166.0519
		L_{max} = 141.672*92.4*1*0.75*1 =	9,817.8713
	Load case 2	W_j = 9.929*141.672 =	1,406.635
		L_{max} = 141.672*92.4*1*0.75*1 =	9,817.8713
	Load case 3	W_j = 11.225*141.672 =	1,590.2287
		L_{max} = 141.672*92.4*1*0.75*1 =	9,817.8713
	Load case 5	W_j = 31.802*141.672 =	4,505.4686
		L_{max} = 141.672*184.8*1*0.75*1 =	19,635.74
	Load case 6	W_j = 36.673*141.672 =	5,195.4937
		L_{max} = 141.672*184.8*1*0.75*1 =	19,635.74
	Load case 7	W_j = 28.442*141.672 =	4,029.4418
		L_{max} = 141.672*184.8*1*0.75*1 =	19,635.74
	Load case 8	W_j = 39.667*141.672 =	***5,619.6705***
		L_{max} = 141.672*184.8*1*0.75*1 =	***19,635.74***
Corroded	Load case 1	W_j = 8.899*141.672 =	1,260.802
		L_{max} = 141.672*92.4*1*0.75*1 =	9,817.8713
	Load case 2	W_j = 10.83*141.672 =	1,534.3631
		L_{max} = 141.672*92.4*1*0.75*1 =	9,817.8713
	Load case 3	W_j = 12.057*141.672 =	1,708.1678
		L_{max} = 141.672*92.4*1*0.75*1 =	9,817.8713
	Load case 5	W_j = 29.945*141.672 =	4,242.3438
		L_{max} = 141.672*184.8*1*0.75*1 =	19,635.74
	Load case 6	W_j = 34.244*141.672 =	4,851.4008
		L_{max} = 141.672*184.8*1*0.75*1 =	19,635.74
	Load case 7	W_j = 25.344*141.672 =	3,590.5988
		L_{max} = 141.672*184.8*1*0.75*1 =	19,635.74
	Load case 8	W_j = 37.402*141.672 =	5,298.7667
		L_{max} = 141.672*184.8*1*0.75*1 =	19,635.74
$\lvert W_j \rvert <= L_{max}$ indicates the joint strength is adequate for the Operating condition.			

ASME Tube To Tubesheet Joint Loads - Periphery Of Bundle			
$W_j = \sigma_{t,o}*A_t$			
$L_{max} = A_t*S_a*f_e*f_r*f_y$			
Condition Tube side hydrotest			**N**
New	Load case 1	W_j = 10.987*141.672 =	1,556.5968
		L_{max} = 141.672*161.1*1*0.75*1 =	17,117.52
	$\lvert W_j \rvert <= L_{max}$ indicates the joint strength is adequate for the Tube side hydrotest condition.		

ASME Tube To Tubesheet Joint Loads - Periphery Of Bundle			
$W_j = \sigma_{t,o}*A_t$			
$L_{max} = A_t*S_a*f_e*f_r*f_y$			
Condition Shell side hydrotest			**N**
New	Load case 2	W_j = 13.236*141.672 =	1,875.2319
		L_{max} = 141.672*161.1*1*0.75*1 =	17,117.52
	$\lvert W_j \rvert <= L_{max}$ indicates the joint strength is adequate for the Shell side hydrotest condition.		

<table>
<tr><td colspan="5">TEMA A.13 Required Effective Tubesheet Thickness
Actual Tubesheet Thickness Used, $T_{Nominal}$ = 130 mm</td></tr>
<tr><td rowspan="2">$T_{\text{Min effective for bending/shear, corr}}$</td><td colspan="4">= $T_{Nominal}$ - Larger (Tube Side Pass Groove Depth, Tube Side Corrosion) - Shell Side Corrosion</td></tr>
<tr><td colspan="4">= 130 - Larger(0, 3) - 3 = 124 mm</td></tr>
<tr><td rowspan="2">$T_{\text{Min effective for bending/shear, new}}$</td><td colspan="4">= $T_{Nominal}$ - Larger (Tube Side Pass Groove Depth, Tube Side Corrosion) - Shell Side Corrosion</td></tr>
<tr><td colspan="4">= 130 - Larger(0, 0) - 0 = 130 mm</td></tr>
<tr><td rowspan="2">$T_{\text{Min effective for flanged extension}}$</td><td colspan="4">= $T_{Nominal}$ - Gasket Confinement Groove Depth</td></tr>
<tr><td colspan="4">= 130 - 22.4 = 107.6 mm</td></tr>
<tr><td rowspan="9">Equations used</td><td colspan="2" rowspan="3">A.131
(bending)</td><td colspan="2">$\eta = 1 - 0.785/(\text{Pitch/Tube OD})^2 = 1 - 0.785/(25.4/19.05)^2 = 0.5584$</td></tr>
<tr><td colspan="2">F = 1</td></tr>
<tr><td colspan="2">$T_{bending} = (F*G/3)*(P/(\eta*S))^{1/2}$</td></tr>
<tr><td colspan="2" rowspan="3">A.132
(shear)</td><td colspan="2">$D_L = 4*A/C$</td></tr>
<tr><td colspan="2">$T_{shear} = 0.31*D_L*(P/S)/(1 - d_o/\text{Pitch})$</td></tr>
<tr><td colspan="2">Shear does not control if $(P/S) < 1.6*(1 - d_o/\text{Pitch})^2$</td></tr>
<tr><td colspan="2" rowspan="3">A.133
(flanged extension)</td><td rowspan="2">r = A/G</td><td>$r_{new,shell\ side}$ = 970/820.25 = 1.1826</td></tr>
<tr><td>$r_{new,tube\ side}$ = 970/820.25 = 1.1826</td></tr>
<tr><td colspan="2">$T_r = 0.98*(M*(r^2 - 1 + 3.71*r^2*\ln(r)) / (S*(A - G)*(1 + 1.86*r^2)))^{0.5}$</td></tr>
<tr><td rowspan="8">Operating</td><td rowspan="4">Corroded</td><td rowspan="2">Shell Side

P is from A.153</td><td colspan="2">$T_{bending} = (1*820.25/3)*(3.61/(0.5584*138))^{1/2}$ = 59.18 mm</td></tr>
<tr><td colspan="2">Shear does not control as $(3.61/138) < 1.6*(1 - 19.05/25.4)^2$</td></tr>
<tr><td rowspan="2">Tube Side

P is from A.154</td><td colspan="2">$T_{bending} = (1*820.25/3)*(4.34/(0.5584*138))^{1/2}$ = 64.91 mm</td></tr>
<tr><td colspan="2">Shear does not control as $(4.34/138) < 1.6*(1 - 19.05/25.4)^2$</td></tr>
<tr><td rowspan="4">New</td><td rowspan="2">Shell Side

P is from A.153</td><td colspan="2">$T_{bending} = (1*820.25/3)*(4.09/(0.5584*138))^{1/2}$ = 62.96 mm</td></tr>
<tr><td colspan="2">Shear does not control as $(3.85/138) < 1.6*(1 - 19.05/25.4)^2$</td></tr>
<tr><td rowspan="2">Tube Side

P is from A.154</td><td colspan="2">$T_{bending} = (1*820.25/3)*(4.64/(0.5584*138))^{1/2}$ = 67.09 mm</td></tr>
<tr><td colspan="2">Shear does not control as $(4.37/138) < 1.6*(1 - 19.05/25.4)^2$</td></tr>
<tr><td rowspan="3">Tube side hydrotest</td><td rowspan="3">New</td><td rowspan="3">Tube Side

P is from A.154</td><td colspan="2">$T_{bending} = (1*820.25/3)*(10.93/(0.5584*223.2))^{1/2}$ = 80.97 mm</td></tr>
<tr><td colspan="2">Shear does not control as $(5.88/223.2) < 1.6*(1 - 19.05/25.4)^2$</td></tr>
<tr><td colspan="2">$T_r = 0.98*(418{,}002.5*1000*(1.1826^2 - 1 + 3.71*1.1826^2*\ln(1.1826)) / (223.2*(970 - 820.25)*(1 + 1.86*1.1826^2)))^{0.5}$ = 65.04 mm</td></tr>
<tr><td>Shell side hydrotest</td><td>New</td><td></td><td colspan="2"></td></tr>
</table>

		Shell Side P is from A.153	$T_{bending}$ = (1*820.25/3)*(4.63/(0.5584*223.2)) $^{1/2}$ = 52.72 mm
			Shear does not control as (4.37/223.2) < 1.6*(1 - 19.05/25.4)^2
			T_r = 0.98*(419,826.7*1000*(1.1826^2 - 1 + 3.71*1.1826^2*ln(1.1826)) / (223.2*(970 - 820.25)*(1 + 1.86*1.1826^2)))$^{0.5}$ = 65.19 mm

TEMA A.151 Equivalent Differential Expansion Pressure, Corroded, Required Thickness		
Equations used	J = 1 for shells without expansion joints.	
	$K = E_s*t_s*(D_o - t_s) / (E_t*t_t*N*(d - t_t))$	
	$\Delta L = L_t*(\alpha_s*(T_m-70) - \alpha_T*(t_m-70))$	from T-4.5
	$F_q = 0.25 + (F - 0.6)*((300*t_s*E_s/(K*L*E))*(G/T)^3)^{0.25}$	
	$P_d = 4*J*E_s*t_s*(\Delta L/L_t)/((D_o - 3*t_s)*(1 + J*K*F_q))$	
Operating	K = 203,998.499*22*(750 - 22) / (201,466.137*2.77*537*(19.05 - 2.77)) = 0.6697	
	ΔL = 12,000*(6.3889E-06*(25.61-70) - 6.4723E-06*(95.018-70)) = -5.35	
	F_q = 0.25 + (1 - 0.6)*((300*22*203,998.499/(0.6697*11,746*201,466.137))*(820.25/64.91) ^{3})$^{0.25}$ **= 2.8239**	
	P_d = 1000*4*1*203,998.5*22*(-5.35/12,000)/((750 - 3*22)*(1 + 1*0.6697*2.8239)) = **-4,044.46 kPa**	

TEMA A.153 Effective Shell Side Design Pressure For Bending, Corroded, Required Thickness			
Equations used	$f_s = 1 - N*(d_o/G)^2$ = 1 - 537*(19.05/820.25)^2 = 0.7104		
	$P_s' = P_s*(0.4*J*(1.5 + K*(1.5 + f_s)) - ((1 - J)/2)*(D_j^2/G^2 - 1))/(1 + J*K*F_q)$		J, K, F_q are from A.151
	P = greatest absolute value of P_1 through P_6	$P_1 = (P_s' - P_d)/2$	P_d is from A.151
		$P_2 = P_s'$	
		$P_3 = P_{Bs}$	P_{Bs} = 0 (bolt moment not present)
		$P_4 = (P_s' - P_d - P_{Bs})/2$	
		$P_5 = (P_{Bs} + P_d)/2$	
		$P_6 = P_s' - P_{Bs}$	
Operating	P_s' = 7,700.01*(0.4*1*(1.5 + 0.6697*(1.5 + 0.7104)) - ((1 - 1)/2) *(820.25^2/820.25^2 - 1))/(1 + 1*0.6697*2.8239) = 3,174.95 kPa		
	P = **3,609.7 kPa** P_{Bs} = 0 P_d = -4,044.46	P_1 = (3,174.95 - -4,044.46)/2 = 3,609.7 kPa	
		P_2 = 3,174.95 kPa	
		P_3 = 0 kPa	
		P_4 = (3,174.95 - -4,044.46 - 0)/2 = 3,609.7 kPa	
		P_5 = (0 + -4,044.46)/2 = -2,022.23 kPa	
		P_6 = 3,174.95 - 0 = 3,174.95 kPa	

TEMA A.154 Effective Tube Side Design Pressure For Bending, Corroded, Required Thickness

Equations used	$f_t = 1 - N*((d_o-2*t_t)/G)^2 = 1 - 537*((19.05-2*2.77)/820.25)^2 = 0.8543$			
	$P_t' = P_t*((1 + 0.4*J*K*(1.5 + f_t))/(1 + J*K*F_q))$			J, K, F_q are from A.151
	P = greatest absolute value of	when P_s' is positive	$P_1 = (P_t' + P_{Bt} + P_d)/2$	P_d is from A.151
			$P_2 = P_t' + P_{Bt}$	P_{Bt} = 0 (bolt moment not present)
		when P_s' is negative	$P_1 = (P_t' - P_s' + P_{Bt} + P_d)/2$	P_s' is from A.153
			$P_2 = P_t' - P_s' + P_{Bt}$	
Operating	P_t' = 7,700.01*((1 + 0.4*1*0.6697*(1.5 + 0.8543))/(1 + 1*0.6697*2.8239)) = 4,342.99 kPa			
	P = **4,342.99 kPa** P_s' = 3,174.95 P_d = -4,044.46 P_{Bt} = 0		P_1 = (4,342.99 + 0 + -4,044.46)/2 = 149.27 kPa	
			P_2 = 4,342.99 + 0 = 4,342.99 kPa	

TEMA A.151 Equivalent Differential Expansion Pressure, New, Required Thickness

Equations used	J = 1 for shells without expansion joints.	
	$K = E_s*t_s*(D_o - t_s) / (E_t*t_t*N*(d - t_t))$	
	$\Delta L = L_t*(\alpha_s*(T_m-70) - \alpha_T*(t_m-70))$	from T-4.5
	$F_q = 0.25 + (F - 0.6)*((300*t_s*E_s/(K*L*E))*(G/T)^3)^{0.25}$	
	$P_d = 4*J*E_s*t_s*(\Delta L/L_t)/((D_o - 3*t_s)*(1 + J*K*F_q))$	
Operating	K = 203,998.499*25*(750 - 25) / (201,466.137*2.77*537*(19.05 - 2.77)) = 0.7579	
	ΔL = 12,000*(6.3889E-06*(25.61-70) - 6.4723E-06*(95.018-70)) = -5.35	
	$\mathbf{F_q}$ = 0.25 + (1 - 0.6)*((300*25*203,998.499/(0.7579*11,740*201,466.137))*(820.25/80.97)^3)$^{0.25}$ = **2.4333**	
	$\mathbf{P_d}$ = 1000*4*1*203,998.5*25*(-5.35/12,000)/((750 - 3*25)*(1 + 1*0.7579*2.4333)) = **-4,734.27 kPa**	
Tube side hydrotest	K = 201,999.998*25*(750 - 25) / (201,999.998*2.77*537*(19.05 - 2.77)) = 0.7485	
	ΔL = 12,000*(6.4167E-06*(77-70) - 6.4167E-06*(77-70)) = 0	
	$\mathbf{F_q}$ = 0.25 + (1 - 0.6)*((300*25*201,999.998/(0.7485*11,740*201,999.998))*(820.25/80.97)^3)$^{0.25}$ = **2.4333**	
	$\mathbf{P_d}$ = 1000*4*1*202,000*25*(0/12,000)/((750 - 3*25)*(1 + 1*0.7485*2.4333)) = **0 kPa**	
Shell side hydrotest	K = 201,999.998*25*(750 - 25) / (201,999.998*2.77*537*(19.05 - 2.77)) = 0.7485	
	ΔL = 12,000*(6.4167E-06*(77-70) - 6.4167E-06*(77-70)) = 0	
	$\mathbf{F_q}$ = 0.25 + (1 - 0.6)*((300*25*201,999.998/(0.7485*11,740*201,999.998))*(820.25/80.97)^3)$^{0.25}$ = **2.4333**	
	$\mathbf{P_d}$ = 1000*4*1*202,000*25*(0/12,000)/((750 - 3*25)*(1 + 1*0.7485*2.4333)) = **0 kPa**	

TEMA A.152 Equivalent Bolting Pressure, New

Equations used	$P_{Bt} = 6.2*M_1/(F^2*G^3)$
	$P_{Bs} = 6.2*M_2/(F^2*G^3)$
Tube side hydrotest	P_{Bt} = 6.2*1e6*418,002.5/(1^2*820.25^3) = 4,695.97 kPa
	P_{Bs} = 6.2*1e6*231,868.2/(1^2*820.25^3) = 2,604.88 kPa
Shell side hydrotest	P_{Bt} = 6.2*1e6*419,826.7/(1^2*820.25^3) = 4,716.46 kPa
	P_{Bs} = 6.2*1e6*232,880.1/(1^2*820.25^3) = 2,616.25 kPa

TEMA A.153 Effective Shell Side Design Pressure For Bending, New, Required Thickness

Equations used	$f_s = 1 - N*(d_o/G)^2 = 1 - 537*(19.05/820.25)^2 = 0.7104$		
	$P_s' = P_s*(0.4*J*(1.5 + K*(1.5 + f_s)) - ((1 - J)/2)*(D_j^2/G^2 - 1))/(1 + J*K*F_q)$		J, K, F_q are from A.151
	P = greatest absolute value of P_1 through P_6	$P_1 = (P_s' - P_d)/2$	P_d is from A.151
		$P_2 = P_s'$	
		$P_3 = P_{Bs}$	P_{Bs} is from A.152
		$P_4 = (P_s' - P_d - P_{Bs})/2$	
		$P_5 = (P_{Bs} + P_d)/2$	
		$P_6 = P_s' - P_{Bs}$	
Operating	P_s' = 7,700.01*(0.4*1*(1.5 + 0.7579*(1.5 + 0.7104)) - ((1 - 1)/2) *($820.25^2/820.25^2$ - 1))/(1 + 1*0.7579*2.4333) = 3,438.54 kPa		
	P = **4,086.41 kPa**	P_1 = (3,438.54 - -4,734.27)/2 = 4,086.41 kPa	
		P_2 = 3,438.54 kPa	
	P_{Bs} = 0	P_3 = 0 kPa	
	P_d = -4,734.27	P_4 = (3,438.54 - -4,734.27 - 0)/2 = 4,086.41 kPa	
		P_5 = (0 + -4,734.27)/2 = -2,367.14 kPa	
		P_6 = 3,438.54 - 0 = 3,438.54 kPa	
Tube side hydrotest	P_s' = 0*(0.4*1*(1.5 + 0.7485*(1.5 + 0.7104)) - ((1 - 1)/2) *($820.25^2/820.25^2$ - 1))/(1 + 1*0.7485*2.4333) = 0 kPa		
	P = **2,604.88 kPa**	P_1 = (0 - 0)/2 = 0 kPa	
		P_2 = 0 kPa	
	P_{Bs} = 2,604.88	P_3 = 2,604.88 kPa	
	P_d = 0	P_4 = (0 - 0 - 2,604.88)/2 = -1,302.44 kPa	
		P_5 = (2,604.88 + 0)/2 = 1,302.44 kPa	
		P_6 = 0 - 2,604.88 = -2,604.88 kPa	
Shell side hydrotest	P_s' = 10,359.65*(0.4*1*(1.5 + 0.7485*(1.5 + 0.7104)) - ((1 - 1)/2) *($820.25^2/820.25^2$ - 1))/(1 + 1*0.7485*2.4333) = 4,633.23 kPa		
	P = **4,633.23 kPa**	P_1 = (4,633.23 - 0)/2 = 2,316.61 kPa	
		P_2 = 4,633.23 kPa	
	P_{Bs} = 2,616.25	P_3 = 2,616.25 kPa	
	P_d = 0	P_4 = (4,633.23 - 0 - 2,616.25)/2 = 1,008.49 kPa	
		P_5 = (2,616.25 + 0)/2 = 1,308.12 kPa	
		P_6 = 4,633.23 - 2,616.25 = 2,016.98 kPa	

<table>
<tr><th colspan="5">TEMA A.154 Effective Tube Side Design Pressure For Bending, New, Required Thickness</th></tr>
<tr><td rowspan="6">Equations used</td><td colspan="4">$f_t = 1 - N*((d_o-2*t_t)/G)^2 = 1 - 537*((19.05-2*2.77)/820.25)^2 = 0.8543$</td></tr>
<tr><td colspan="3">$P_t' = P_t*((1 + 0.4*J*K*(1.5 + f_t))/(1 + J*K*F_q))$</td><td>J, K, F_q are from A.151</td></tr>
<tr><td rowspan="4">P = greatest absolute value of</td><td rowspan="2">when P_s' is positive</td><td>$P_1 = (P_t' + P_{Bt} + P_d)/2$</td><td>$P_d$ is from A.151</td></tr>
<tr><td>$P_2 = P_t' + P_{Bt}$</td><td>P_{Bt} is from A.152</td></tr>
<tr><td rowspan="2">when P_s' is negative</td><td>$P_1 = (P_t' - P_s' + P_{Bt} + P_d)/2$</td><td rowspan="2">$P_s'$ is from A.153</td></tr>
<tr><td>$P_2 = P_t' - P_s' + P_{Bt}$</td></tr>
<tr><td rowspan="3">Operating</td><td colspan="4">P_t' = 7,700.01*((1 + 0.4*1*0.7579*(1.5 + 0.8543))/(1 + 1*0.7579*2.4333)) = 4,639.65 kPa</td></tr>
<tr><td colspan="2" rowspan="2">P = 4,639.65 kPa

P_s' = 3,438.54
P_d = -4,734.27
P_{Bt} = 0</td><td colspan="2">P_1 = (4,639.65 + 0 + -4,734.27)/2 = -47.31 kPa</td></tr>
<tr><td colspan="2">P_2 = 4,639.65 + 0 = 4,639.65 kPa</td></tr>
<tr><td rowspan="3">Tube side hydrotest</td><td colspan="4">P_t' = 10,314.63*((1 + 0.4*1*0.7485*(1.5 + 0.8543))/(1 + 1*0.7485*2.4333)) = 6,233.13 kPa</td></tr>
<tr><td colspan="2" rowspan="2">P = 10,929.1 kPa

P_s' = 0
P_d = 0
P_{Bt} = 4,695.97</td><td colspan="2">P_1 = (6,233.13 + 4,695.97 + 0)/2 = 5,464.55 kPa</td></tr>
<tr><td colspan="2">P_2 = 6,233.13 + 4,695.97 = 10,929.1 kPa</td></tr>
<tr><td rowspan="3">Shell side hydrotest</td><td colspan="4">P_t' = 0*((1 + 0.4*1*0.7485*(1.5 + 0.8543))/(1 + 1*0.7485*2.4333)) = 0 kPa</td></tr>
<tr><td colspan="2" rowspan="2">P = 4,716.46 kPa

P_s' = 4,633.23
P_d = 0
P_{Bt} = 4,716.46</td><td colspan="2">P_1 = (0 + 4,716.46 + 0)/2 = 2,358.23 kPa</td></tr>
<tr><td colspan="2">P_2 = 0 + 4,716.46 = 4,716.46 kPa</td></tr>
</table>

Tubesheet Maximum Pressure Report

ASME Tubesheet Maximum Pressure Ratings

Description		Operating	Tube side MAP	Shell side MAP
Tube Side	Pressure (kPa)	8,970.11	9,665.9	0
	Tubesheet Static Pressure (kPa)	0	0	0
	Design temperature (°C)	85	25	25
Shell Side	Pressure (kPa)	17,365.01	0	18,255.68
	Tubesheet Static Pressure (kPa)	0	0	0
	Design temperature (°C)	85	25	25
Tubes	Design temperature (°C)	85	25	25
	Mean temperature (°C)	35.01	25	25
Shell	Mean temperature (°C)	-3.55	25	25
Tubesheet	Design temperature (°C)	85	25	25
	Mean temperature (°C)	35.01	25	25

TEMA Tubesheet Maximum Pressure Ratings

Description		Operating	Tube side MAP	Shell side MAP
Tube Side	Pressure (kPa)	20,451.11	20,684.11	0
	Tubesheet Static Pressure (kPa)	0	0	0
	Design temperature (°C)	85	25	25
Shell Side	Pressure (kPa)	20,684.11	0	20,684.11
	Tubesheet Static Pressure (kPa)	0	0	0
	Design temperature (°C)	85	25	25
Tubes	Design temperature (°C)	85	25	25
	Mean temperature (°C)	35.01	25	25
Shell	Mean temperature (°C)	-3.55	25	25
Tubesheet	Design temperature (°C)	85	25	25
	Mean temperature (°C)	35.01	25	25