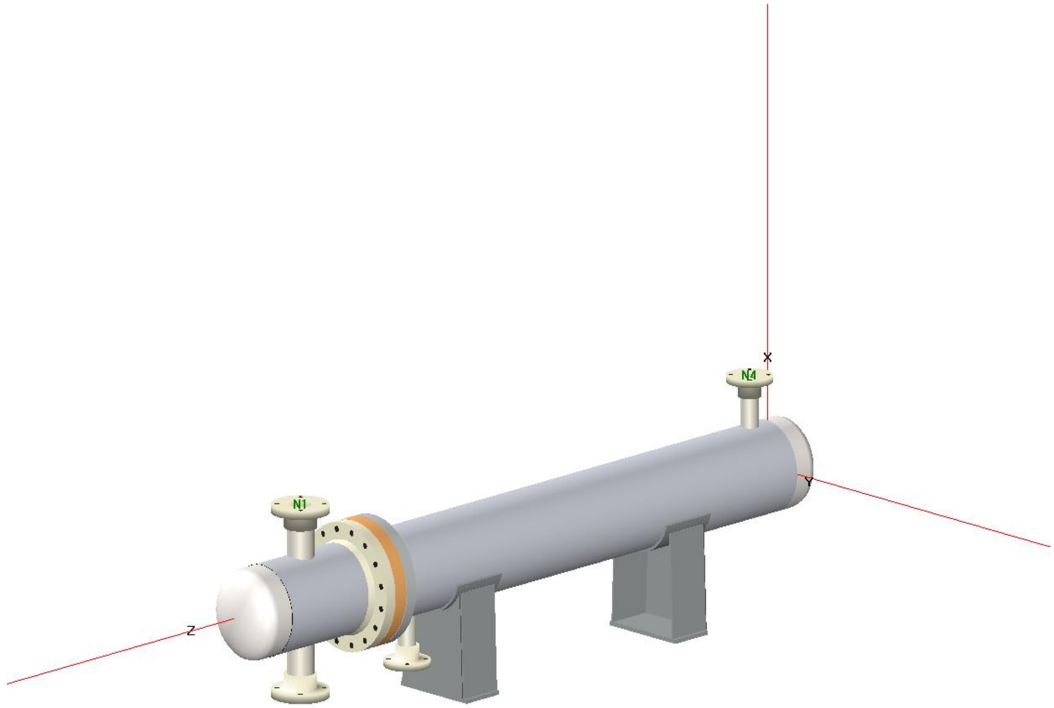
Codeware, Inc.

Sarasota, FL, USA

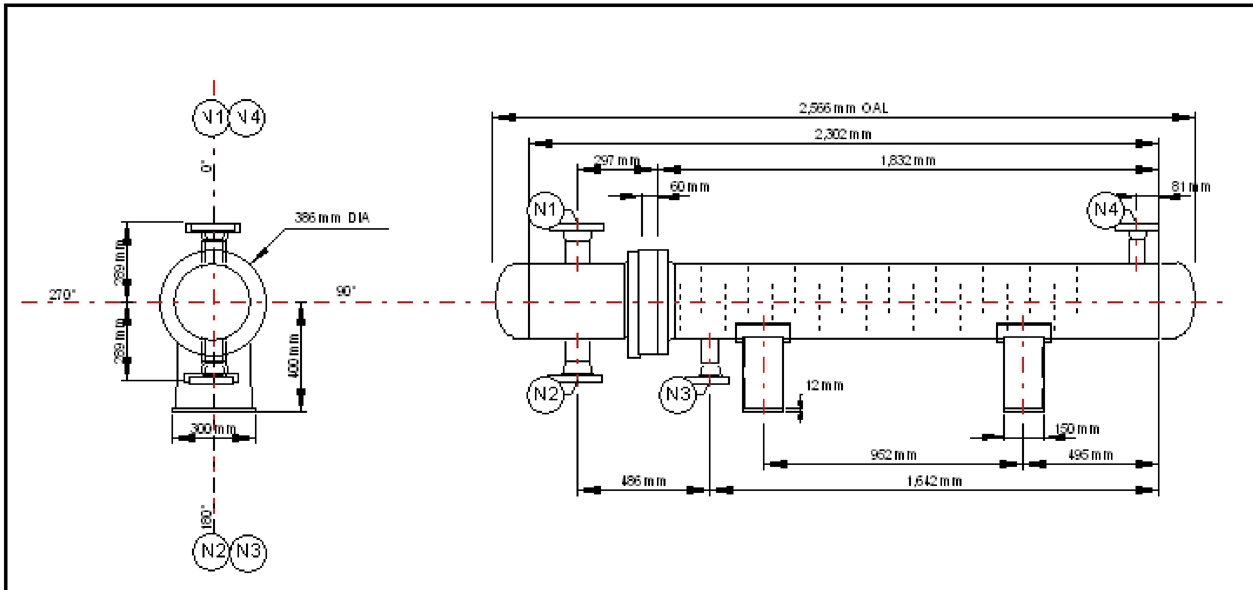
www.codeware.com



COMPRESS Pressure Vessel Design Calculations

Item: Split Stream Dearator
Vessel No: V-1234
Customer: Magaladon Oil Venture
Contract: C-45490-R56
Designer: John Doe
Date: April 1, 2001

You can edit this page by selecting ***Cover Page settings...*** in the ***report*** menu.



DESIGN DATA	SHELL	TUBE
Design Pressure	1,100 kPa	750 kPa
Vacuum Pressure	N/A	N/A
Test Pressure (Shop)	1,430 kPa	2,054 kPa
Design Temperature	65 °C	150 °C
MDMT	-29 °C	-29 °C
Corrosion Allowance	3 mm	0 mm
Number of Passes	1	2
Radiography	RT1	RT1
PWHT	None	None

Estimated Weights

Dry: 435 kg Wet 435 kg
Bundle: 88 kg
Weight at left saddle: 363 kg (Open), 446 kg (Test)
Weight at right saddle: 72 kg (Open), 104 kg (Test)

Materials

Channel: SA-106 B Smls. Pipe
Shell: SA-106 B Smls. Pipe
Tubesheets: SA-266 2
Baffles: SA-36
Tubes: SA-179 Smls. Tube

Tubes (30) 25.4 mm OD x 2.77 mm x 1,700 mm LONG
Tube Pitch = 31.75 mm Triangular (30°)
Tube Surface Area = 4 m²

Gaskets:

NOZZLE SCHEDULE

MARK	NOZZLE	SIZE & SCH	FLANGE	MARK	NOZZLE	SIZE & SCH	FLANGE
N4	SS Outlet	NPS 2 Sch 80 (XS)	NPS 2 WN Class 1				
N3	SS Inlet	NPS 2 Sch 80 (XS)	NPS 2 WN Class 1				
N2	TS Outlet	NPS 3 Sch 40 (Std)	NPS 3 WN Class 1				
N1	TS Inlet	NPS 3 Sch 40 (Std)	NPS 3 WN Class 1				

REVISIONS

REV	DATE	DESCRIPTION
0	06/18/2012	FOR APPROV

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

ASME VIII-1 A2011 TEMA Type: BEU
Size: 10-66.9291 TEMA Class: R
DWN BY:
CHK BY:
DATE:

General Arrangeme

DWG NO. 145685-1 Rev 0

E-7603.CW7

Deficiencies Summary

Deficiencies for Heat Exchanger
Front tubesheet: Rated MDMT of -13.41 °C is warmer than the required -29 °C

Warnings Summary

Warnings for SS Inlet (N3)
The attached ASME B16.5 flange limits the nozzle MAP. (warning)

Warnings for SS Outlet (N4)
The attached ASME B16.5 flange limits the nozzle MAP. (warning)

Warnings for TS Inlet (N1)
The attached ASME B16.5 flange limits the nozzle MAWP. (warning)
The attached ASME B16.5 flange limits the nozzle MAP. (warning)

Warnings for TS Outlet (N2)
The attached ASME B16.5 flange limits the nozzle MAWP. (warning)
The attached ASME B16.5 flange limits the nozzle MAP. (warning)

ASME B16.5 / B16.47 Flange Warnings Summary

ASME B16.5 / 16.47 Flanges with Warnings

Flange	Applicable Warnings
TS Inlet (N1)	1
TS Outlet (N2)	1
SS Inlet (N3)	1
SS Outlet (N4)	1

ASME B16.5 / 16.47 Flange Warnings

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

Nozzle Schedule

Nozzle mark	Service	Size	Materials								
			Nozzle	Impact	Norm	Fine Grain	Pad	Impact	Norm	Fine Grain	Flange
N1	TS Inlet	NPS 3 Sch 40 (Std) DN 80	SA-106 B Smls. Pipe	No	No	No	SA-516 70	No	No	No	WN A105 Class 150
N2	TS Outlet	NPS 3 Sch 40 (Std) DN 80	SA-106 B Smls. Pipe	No	No	No	SA-516 70	No	No	No	WN A105 Class 150
N3	SS Inlet	NPS 2 Sch 80 (XS) DN 50	SA-106 B Smls. Pipe	No	No	No	SA-516 70	No	No	No	WN A105 Class 150
N4	SS Outlet	NPS 2 Sch 80 (XS) DN 50	SA-106 B Smls. Pipe	No	No	No	SA-516 70	No	No	No	WN A105 Class 150

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	88.9	5.49	5.44	Yes	Yes	9.27	N/A		50	9	3	Exempt
N2	88.9	5.49	5.44	Yes	Yes	9.27	N/A		50	9	3	Exempt
N3	60.32	5.54	5.54	Yes	Yes	9.27	N/A		50	9	3	Exempt
N4	60.32	5.54	5.54	Yes	Yes	9.27	N/A		50	9	3	Exempt

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>750</td><td>150</td><td>5,824.93</td><td>8,533.65</td><td>N/A</td><td>150</td><td>-105</td><td colspan="2">Note 1</td><td>No</td></tr>
<tr><td>Straight Flange on Front Head</td><td>750</td><td>150</td><td>5,520.64</td><td>8,235.84</td><td>N/A</td><td>150</td><td>-105</td><td colspan="2">Note 2</td><td>No</td></tr>
<tr><td>Front Channel</td><td>750</td><td>150</td><td>4,523.85</td><td>7,244.28</td><td>N/A</td><td>150</td><td>-105</td><td colspan="2">Note 3</td><td>No</td></tr>
<tr><td>Tubesheet</td><td>750</td><td>150</td><td>18,155.21</td><td>24,386.47</td><td>18,155.21</td><td>150</td><td>-13.41</td><td colspan="2">Note 4</td><td>No</td></tr>
<tr><td>Tubes</td><td>750</td><td>150</td><td>19,091.64</td><td>19,091.64</td><td>12,099.66</td><td>150</td><td>-105</td><td colspan="2">Note 5</td><td>No</td></tr>
<tr><td>Tube Side Flange (front)</td><td>750</td><td>150</td><td>3,598.11</td><td>4,284.78</td><td>N/A</td><td>150</td><td>-48</td><td colspan="2">Note 6</td><td>No</td></tr>
<tr><td>Tube Side Flange (front) - Flange Hub</td><td>750</td><td>150</td><td>6,456.62</td><td>9,631.75</td><td>N/A</td><td>150</td><td>-105</td><td colspan="2">Note 7</td><td>No</td></tr>
<tr><td rowspan="2">TS Inlet (N1)</td><td rowspan="2">750</td><td rowspan="2">150</td><td rowspan="2">1,580</td><td rowspan="2">1,960</td><td rowspan="2">N/A</td><td rowspan="2">150</td><td rowspan="2">-39.89</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">TS Outlet (N2)</td><td rowspan="2">750</td><td rowspan="2">150</td><td rowspan="2">1,580</td><td rowspan="2">1,960</td><td rowspan="2">N/A</td><td rowspan="2">150</td><td rowspan="2">-39.89</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 -13.41 °C @ 1,580 kPa

Chamber MAWP hot & corroded is 1,580 kPa @ 150 °C

Chamber MAP cold & new is 1,960 kPa @ 21.11 °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	1,100	150	18,155.21	29,125.26	18,155.21	150	-13.41	Note 4		No
Shell	1,100	65	4,523.85	7,244.28	N/A	65	-105	Note 10		No
Straight Flange on Rear Shell Head	1,100	65	5,520.64	8,235.84	N/A	65	-105	Note 12		No
Rear Shell Head	1,100	65	5,824.93	8,533.65	N/A	65	-105	Note 11		No
Tubes	750	150	12,099.66	12,099.66	19,091.64	150	N/A	N/A		No
Shell Side Flange (front)	1,100	65	3,598.19	4,612.83	N/A	65	-48	Note 13		No
Shell Side Flange (front) - Flange Hub	1,100	65	6,456.62	9,631.75	N/A	65	-105	Note 14		No
Saddle	1,100	65	1,100	N/A	N/A	N/A	N/A	N/A		N/A
SS Inlet (N3)	1,100	65	1,657.56	1,960	N/A	65	-48	Nozzle	Note 8	No
								Pad	Note 15	No
SS Outlet (N4)	1,100	65	1,657.56	1,960	N/A	65	-48	Nozzle	Note 8	No
								Pad	Note 15	No

Chamber design MDMT is -29 °C
Chamber rated MDMT is -13.41 °C @ 1,100 kPa

Chamber MAWP hot & corroded is 1,100 kPa @ 65 °C

Chamber MAP cold & new is 1,960 kPa @ 21.11 °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 to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2804)	
3.	Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.344)	
4.	Tubesheet impact test exemption temperature from Fig UCS-66M Curve B = -13.41 °C	UCS-66 governing thickness = 16.75 mm.
5.	Material is impact test exempt per UCS-66(d) (NPS 4 or smaller pipe)	
6.	UCS-66(b)(1)(b) has been applied. Flange impact test exemption temperature from Fig UCS-66M Curve B = -29 °C Fig UCS-66.1M MDMT reduction = 65.8 °C, (coincident ratio = 0.3687) Rated MDMT of -94.8°C is limited to -48°C by UCS-66(b)(2) UCS-66 governing thickness = 8.11 mm	Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C
7.	Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2395)	
8.	Flange rating governs:	UCS-66(b)(1)(b)
9.	Pad is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.3441).	
10.	Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2389)	
11.	Straight Flange governs MDMT	
12.	Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.1947)	
13.	UCS-66(b)(1)(b) has been applied. Flange is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2385)	Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C
14.	Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.1664)	
15.	Pad is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2389).	

Design notes are available on the Settings Summary page.

Revision History

No.	Date	Operator	Notes
0	6/18/2012	20019413	New vessel created Heat Exchanger. [COMPRESS 2012 Build 7200]

Settings Summary

COMPRESS 2012 Build 7200

Units: SI

Datum Line Location: 0.00 mm from right seam

Design

ASME Section VIII Division 1, 2010 Edition, A11 Addenda 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 α > 30 only:	Yes
Preheat P-No 1 Materials > 1.25&#34 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

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

Code Cases\Interpretations

Use Code Case 2547:	No
Apply interpretation VIII-1-83-66:	Yes
Apply interpretation VIII-1-86-175:	Yes
Apply interpretation VIII-1-83-115:	Yes
Apply interpretation VIII-1-01-37:	Yes
No UCS-66.1 MDMT reduction:	No
No UCS-68(c) MDMT reduction:	No

Disallow UG-20(f) exemptions: Yes

UG-22 Loadings

UG-22(a) Internal or External Design Pressure :	Yes
UG-22(b) Weight of the vessel and normal contents under operating or test conditions:	Yes
UG-22(c) Superimposed static reactions from weight of attached equipment (external loads):	No
UG-22(d)(2) Vessel supports such as lugs, rings, skirts, saddles and legs:	Yes
UG-22(f) Wind reactions:	No
UG-22(f) Seismic reactions:	No
UG-22(j) Test pressure and coincident static head acting during the test:	No

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

Thickness Summary

Component Identifier	Material	Diameter (mm)	Length (mm)	Nominal t (mm)	Design t (mm)	Total Corrosion (mm)	Joint E	Load
Front Head	SA-234 WPB	254.51 ID	72.9	9.27*	3.8	3	1.00	Internal
Straight Flange on Front Head	SA-234 WPB	254.51 ID	58.7	9.27	3.83	3	1.00	Internal
Front Channel	SA-106 B Smls. Pipe	254.51 ID	348	9.27	3.83	3	1.00	Internal
Tubesheet	SA-266 2	386 OD	67	67	22.46	6	1.00	Unknown
Tubes	SA-179 Smls. Tube	25.4 OD	1,700	2.77	0.49	0	1.00	External
Shell	SA-106 B Smls. Pipe	254.51 ID	1,769	9.27	4.22	3	1.00	Internal
Straight Flange on Rear Shell Head	SA-234 WPB	254.51 ID	58.7	9.27	4.22	3	1.00	Internal
Rear Shell Head	SA-234 WPB	254.51 ID	72.9	9.27*	4.18	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	9.5	6.5	0	0	0	0	0	0	5.1	5.5	0.14
Front Channel	20	13.7	0	0	0	0	0	0	21.7	22.9	0.29
Tubesheet	60.6	47.2	0	0	0	0	0	0	0	0	0.2
Shell	106	72.5	0	0	0	0	0	0	65.7	70.2	1.51
Tubes	87.9	87.9	0	0	0	0	0	0	17.6	17.6	N/A
Rear Shell Head	9.5	6.5	0	0	0	0	0	0	5.1	5.5	0.14
Saddle	32.7	32.7	0	0	0	0	0	0	0	0	0.88
TOTAL:	**326.2**	**267.1**	**0**	**0**	**0**	**0**	**0**	**0**	**115.3**	**121.7**	**3.16**

* 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	Tray Supports	Rings & Clips	Vertical Loads	
	New	Corroded	New	Corroded						
Front Head	0	0	0	0	0	0	0	0	0	0
Front Channel	22.4	21.2	14.4	13.2	0	0	0	0	0	0.24
Tubesheet	0	0	0	0	0	0	0	0	0	0
Shell	22.4	21.2	9.4	8.6	0	40.3[1]	0	0	0	0.19
Rear Shell Head	0	0	0	0	0	0	0	0	0	0
TOTAL:	**44.7**	**42.4**	**23.8**	**21.8**	**0**	**40.3**	**0**	**0**	**0**	**0.29**

Vessel operating weight, Corroded: 372 kg
Vessel operating weight, New: 435 kg
Vessel empty weight, Corroded: 372 kg
Vessel empty weight, New: 435 kg
Vessel test weight, New: 550 kg
Vessel test weight, Corroded: 493 kg
Vessel surface area: 3.45 m^2

Vessel center of gravity location - from datum - lift condition

Vessel Lift Weight, New: 435 kg
Center of Gravity: 1,271.16 mm

Vessel Capacity

Shell side Capacity** (New): 71 liters
Shell side Capacity** (Corroded): 75 liters
Tube side Capacity** (New): 44 liters
Tube side Capacity** (Corroded): 45 liters

**The shell and tube capacity does not include volume of nozzle, piping or other attachments.

[1]Baffle weights are approximated.

Hydrostatic Test

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

Shop hydrostatic test gauge pressure is 2,054 kPa at 21.11 °C (the chamber MAWP = 1,580 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
Front Head (1)	2,058.08	4.08	1	1.30
Straight Flange on Front Head	2,058.08	4.08	1	1.30
Front Channel	2,058.08	4.08	1	1.30
Tubes	2,057.97	3.96	1	1.30
Tube Side Flange (front)	2,058.08	4.08	1	1.30
Tubesheet	2,058.08	4.08	1	1.30
TS Inlet (N1)	2,055.5	1.49	1	1.30
TS Outlet (N2)	2,059.66	5.66	1	1.30

Notes:
(1) Front Head limits the UG-99(b) stress ratio.
(2) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

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

The test temperature of 21.11 °C is warmer than the minimum recommended temperature of 3.59 °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 1,430 kPa at 21.11 °C (the chamber MAWP = 1,100 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
Shell (1)	1,434.08	4.08	1	1.30
Straight Flange on Rear Shell Head	1,434.08	4.08	1	1.30
Rear Shell Head	1,434.08	4.08	1	1.30
Tubes	1,433.96	3.96	N/A	1.30
Tubesheet	1,434.08	4.08	1	1.30
Shell Side Flange (front)	1,434.08	4.08	1	1.30
SS Inlet (N3)	1,435.66	5.66	1	1.30
SS Outlet (N4)	1,431.49	1.49	1	1.30

Notes:
(1) Shell limits the UG-99(b) stress ratio.
(2) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

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

The test temperature of 21.11 °C is warmer than the minimum recommended temperature of 3.59 °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	-	2,434	N/A
-	1/3 depth of Front Head	2,383.31	N/A
Straight Flange on Front Head Left	-	2,361.1	491.51
Straight Flange on Front Head Right	-	2,302.4	491.51
Front Channel Left	-	2,302.4	491.51
Front Channel Right	-	1,954.4	491.51
Tubesheet	-	1,900.2	N/A
-	Tube Side Flange (front)	1,891.8	N/A
-	Shell Side Flange (front)	1,831.6	N/A
Shell Left	-	1,769	1,912.51
Shell Right	-	0	1,912.51
Straight Flange on Rear Shell Head Left	-	0	1,912.51
Straight Flange on Rear Shell Head Right	-	-58.7	1,912.51
-	1/3 depth of Rear Shell Head	-80.91	N/A
Rear Shell Head	-	-131.6	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, 2010 Edition, A11 Addenda Metric

Component:	Cylinder
Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Pipe Description:	NPS 10 Sch 40 (Std) DN 250

Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.344)

Internal design pressure: P = 750 kPa @ 150 °C

Static liquid head:

P_{th} = 4.08 kPa (SG = 1, H_s = 416.18 mm, Horizontal test head)

Corrosion allowance   Inner C = 3 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

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

Estimated weight	New = 20 kg	corr = 13.7 kg
Capacity	New = 17.7 liters	corr = 18.55 liters

ID = 254.51 mm
Length L_c = 348 mm
t = 9.27 mm

Design thickness, (at 150 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 750*130.25 / (118,000*1.00 - 0.60*750) + 3
= 3.83 mm

Maximum allowable working pressure, (at 150 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 118,000*1.00*5.11 / (130.25 + 0.60*5.11) - 0
= 4,523.85 kPa

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 118,000*1.00*8.11 / (127.25 + 0.60*8.11)
= 7,244.28 kPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 5.11)
	=	0.004680
B	=	118.1 MPa
S	=	118 / 1.00 = 118 MPa
S_{cHC}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 8.11)
	=	0.007427
B	=	119.49 MPa
S	=	118 / 1.00 = 118 MPa
S_{cHN}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 8.11)
	=	0.007427
B	=	119.49 MPa
S	=	118 / 1.00 = 118 MPa
S_{cCN}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 5.11)
	=	0.004680
B	=	118.1 MPa
S	=	118 / 1.00 = 118 MPa
S_{cCC}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 5.11)
	=	0.004680
B	=	118.1 MPa
S	=	118 / 1.00 = 118 MPa
S_{cVC}	=	min(B, S) = 118 MPa

Shell

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric

Component:	Cylinder
Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Pipe Description:	NPS 10 Sch 40 (Std) DN 250

Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2389)

Internal design pressure: P = 1,100 kPa @ 65 °C

Static liquid head:

P_{th} = 4.08 kPa (SG = 1, H_s = 416.18 mm, Horizontal test head)

Corrosion allowance   Inner C = 3 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

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

Estimated weight	New = 106 kg	corr = 72.5 kg
Capacity	New = 63.11 liters	corr = 67.4 liters

ID = 254.51 mm
Length L_c = 1,769 mm
t = 9.27 mm

Design thickness, (at 65 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 1,100*130.26 / (118,000*1.00 - 0.60*1,100) + 3
= 4.22 mm

Maximum allowable working pressure, (at 65 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 118,000*1.00*5.11 / (130.26 + 0.60*5.11) - 0
= 4,523.85 kPa

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 118,000*1.00*8.11 / (127.26 + 0.60*8.11)
= 7,244.28 kPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.53 / 5.11)
	=	0.004680
B	=	118.1 MPa
S	=	118 / 1.00 = 118 MPa
S_{cHC}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.53 / 8.11)
	=	0.007427
B	=	119.49 MPa
S	=	118 / 1.00 = 118 MPa
S_{cHN}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.53 / 8.11)
	=	0.007427
B	=	119.49 MPa
S	=	118 / 1.00 = 118 MPa
S_{cCN}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.53 / 5.11)
	=	0.004680
B	=	118.1 MPa
S	=	118 / 1.00 = 118 MPa
S_{cCC}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.53 / 5.11)
	=	0.004680
B	=	118.1 MPa
S	=	118 / 1.00 = 118 MPa
S_{cVC}	=	min(B, S) = 118 MPa

Front Head

ASME Section VIII, Division 1, 2010 Edition, A11 Addenda Metric

Component:	Ellipsoidal Head
Material Specification:	SA-234 WPB (II-D Metric p.10, ln. 42)

Straight Flange governs MDMT

Internal design pressure: P = 750 kPa @ 150 °C

Static liquid head:

P_s= 0 kPa (SG=1, H_s=0 mm Operating head)
P_{th}= 4.08 kPa (SG=1, H_s=416.18 mm Horizontal test head)

Corrosion allowance: Inner C = 3 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
	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 = 9.5 kg	corr = 6.5 kg
Capacity*:	new = 5.1 liters	corr = 5.5 liters

* includes straight flange

Inner diameter	=	254.51 mm
Minimum head thickness	=	9.27 mm
Head ratio D/2h	=	2 (new)
Head ratio D/2h	=	1.955 (corroded)
Straight flange length L_{sf}	=	58.7 mm
Nominal straight flange thickness t_{sf}	=	9.27 mm

Results Summary

The governing condition is UG-16.

Minimum thickness per UG-16	=	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	=	3.8 mm
Maximum allowable working pressure (MAWP)	=	5,824.93 kPa
Maximum allowable pressure (MAP)	=	8,533.65 kPa

K (Corroded)

K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (260.51 / (2*66.63))^2]=0.97032

K (New)

K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (254.51 / (2*63.63))^2]=1

Design thickness for internal pressure, (Corroded at 150 °C) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 750*260.51*0.97032 / (2*117,999.995*1 - 0.2*750) + 3
= 3.8 mm

The head internal pressure design thickness is 3.8 mm.

Maximum allowable working pressure, (Corroded at 150 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*117,999.995*1*6.27 / (0.97032*260.51 +0.2*6.27) - 0
= 5,824.93 kPa

The maximum allowable working pressure (MAWP) is 5,824.93 kPa.

Maximum allowable pressure, (New at 21.11 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*117,999.995*1*9.27 / (1*254.51 +0.2*9.27) - 0
= 8,533.65 kPa

The maximum allowable pressure (MAP) is 8,533.65 kPa.

Straight Flange on Front Head

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric

Component: Straight Flange
Material specification: SA-234 WPB (II-D Metric p. 10, ln. 42)
Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2804)

Internal design pressure: P = 750 kPa @ 150 °C

Static liquid head:

P_{th} = 4.08 kPa (SG = 1, H_s = 416.18 mm, Horizontal test head)

Corrosion allowance Inner C = 3 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

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

Estimated weight	New = 3.5 kg	corr = 2.4 kg
Capacity	New = 2.99 liters	corr = 3.13 liters

ID = 254.51 mm
Length L_c = 58.7 mm
t = 9.27 mm

Design thickness, (at 150 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 750*130.25 / (118,000*1.00 - 0.60*750) + 3
= 3.83 mm

Maximum allowable working pressure, (at 150 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 118,000*1.00*6.27 / (130.25 + 0.60*6.27) - 0
= 5,520.64 kPa

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 118,000*1.00*9.27 / (127.25 + 0.60*9.27)
= 8,235.84 kPa

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

A = 0.125 / (R_o / t)
= 0.125 / (136.52 / 6.27)

	=	0.005741
B	=	119.17 MPa
S	=	118 / 1.00 = 118 MPa
S_{cHC}	=	min(B, S) = 118 MPa

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

A	=	$0.125 / (R_o / t)$
	=	0.125 / (136.52 / 9.27)
	=	0.008487
B	=	119.65 MPa
S	=	118 / 1.00 = 118 MPa
S_{cHN}	=	min(B, S) = 118 MPa

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

A	=	$0.125 / (R_o / t)$
	=	0.125 / (136.52 / 9.27)
	=	0.008487
B	=	119.65 MPa
S	=	118 / 1.00 = 118 MPa
S_{cCN}	=	min(B, S) = 118 MPa

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

A	=	$0.125 / (R_o / t)$
	=	0.125 / (136.52 / 6.27)
	=	0.005741
B	=	119.17 MPa
S	=	118 / 1.00 = 118 MPa
S_{cCC}	=	min(B, S) = 118 MPa

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

A	=	$0.125 / (R_o / t)$
	=	0.125 / (136.52 / 6.27)
	=	0.005741
B	=	119.17 MPa
S	=	118 / 1.00 = 118 MPa
S_{cVC}	=	min(B, S) = 118 MPa

Straight Flange on Rear Shell Head

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric

Component: Straight Flange
Material specification: SA-234 WPB (II-D Metric p. 10, ln. 42)
Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.1947)

Internal design pressure: P = 1,100 kPa @ 65 °C

Static liquid head:

P_{th} = 4.08 kPa (SG = 1, H_s = 416.18 mm, Horizontal test head)

Corrosion allowance Inner C = 3 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

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

Estimated weight	New = 3.5 kg	corr = 2.4 kg
Capacity	New = 2.99 liters	corr = 3.13 liters

ID = 254.51 mm
Length L_c = 58.7 mm
t = 9.27 mm

Design thickness, (at 65 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 1,100*130.25 / (118,000*1.00 - 0.60*1,100) + 3
= 4.22 mm

Maximum allowable working pressure, (at 65 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 118,000*1.00*6.27 / (130.25 + 0.60*6.27) - 0
= 5,520.64 kPa

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 118,000*1.00*9.27 / (127.25 + 0.60*9.27)
= 8,235.84 kPa

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

A = 0.125 / (R_o / t)
= 0.125 / (136.52 / 6.27)

	=	0.005741
B	=	119.17 MPa
S	=	118 / 1.00 = 118 MPa
S_{cHC}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 9.27)
	=	0.008487
B	=	119.65 MPa
S	=	118 / 1.00 = 118 MPa
S_{cHN}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 9.27)
	=	0.008487
B	=	119.65 MPa
S	=	118 / 1.00 = 118 MPa
S_{cCN}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 6.27)
	=	0.005741
B	=	119.17 MPa
S	=	118 / 1.00 = 118 MPa
S_{cCC}	=	min(B, S) = 118 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.52 / 6.27)
	=	0.005741
B	=	119.17 MPa
S	=	118 / 1.00 = 118 MPa
S_{cVC}	=	min(B, S) = 118 MPa

Rear Shell Head

ASME Section VIII, Division 1, 2010 Edition, A11 Addenda Metric

Component:	Ellipsoidal Head
Material Specification:	SA-234 WPB (II-D Metric p.10, ln. 42)

Straight Flange governs MDMT

Internal design pressure: P = 1,100 kPa @ 65 °C

Static liquid head:

P_s= 0 kPa (SG=1, H_s=0 mm Operating head)
P_{th}= 4.08 kPa (SG=1, H_s=416.18 mm Horizontal test head)

Corrosion allowance: Inner C = 3 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
	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 = 9.5 kg	corr = 6.5 kg
Capacity*:	new = 5.1 liters	corr = 5.5 liters

* includes straight flange

Inner diameter	=	254.51 mm
Minimum head thickness	=	9.27 mm
Head ratio D/2h	=	2 (new)
Head ratio D/2h	=	1.955 (corroded)
Straight flange length L_{sf}	=	58.7 mm
Nominal straight flange thickness t_{sf}	=	9.27 mm

Results Summary

The governing condition is UG-16.

Minimum thickness per UG-16	=	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	=	4.18 mm
Maximum allowable working pressure (MAWP)	=	5,824.93 kPa
Maximum allowable pressure (MAP)	=	8,533.65 kPa

K (Corroded)

$K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (260.51 / (2*66.63))^2]=0.97032$

K (New)

$K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (254.51 / (2*63.63))^2]=1$

Design thickness for internal pressure, (Corroded at 65 °C) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 1,100*260.51*0.97032 / (2*117,999.995*1 - 0.2*1,100) + 3
= 4.18 mm

The head internal pressure design thickness is 4.18 mm.

Maximum allowable working pressure, (Corroded at 65 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*117,999.995*1*6.27 / (0.97032*260.51 +0.2*6.27) - 0
= 5,824.93 kPa

The maximum allowable working pressure (MAWP) is 5,824.93 kPa.

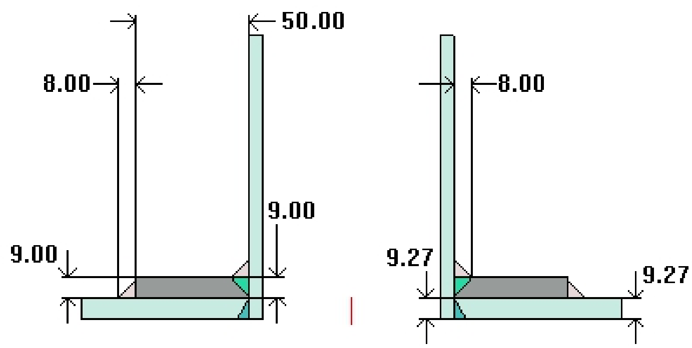
Maximum allowable pressure, (New at 21.11 °C) Appendix 1-4(c)

P = 2*S*E*t / (K*D + 0.2*t) - P_s
= 2*117,999.995*1*9.27 / (1*254.51 +0.2*9.27) - 0
= 8,533.65 kPa

The maximum allowable pressure (MAP) is 8,533.65 kPa.

TS Inlet (N1)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 9.27 mm
Leg_{41} = 8 mm
$t_{w(upper)}$ = 9 mm
Leg_{42} = 8 mm
D_p = 188.9 mm
t_e = 9 mm

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

Located on:	Front Channel
Liquid static head included:	0 kPa
Nozzle material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	NPS 3 Sch 40 (Std) DN 80
Pad material specification:	SA-516 70 (II-D Metric p. 18, ln. 19)
Pad diameter:	188.9 mm
Flange description:	NPS 3 Class 150 WN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Flange rated MDMT:	-39.89°C
(UCS-66(b)(1)(b))	
Liquid static head on flange:	0 kPa
ASME B16.5-2009 flange rating MAWP:	1,580 kPa @ 150°C
ASME B16.5-2009 flange rating MAP:	1,960 kPa @ 21.11°C
ASME B16.5-2009 flange hydro test:	3,000 kPa @ 21.11°C
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1
Nozzle orientation:	0°
Local vessel minimum thickness:	8.11 mm
Nozzle center line offset to datum line:	2,128.4 mm
End of nozzle to shell center:	288.93 mm
Nozzle inside diameter, new:	77.93 mm
Nozzle nominal wall thickness:	5.49 mm
Nozzle corrosion allowance:	3 mm
Projection available outside vessel, Lpr:	82.55 mm
Projection available outside vessel to flange face, Lf:	152.4 mm
Pad is split:	No

Reinforcement Calculations for Internal Pressure

The attached ASME B16.5 flange limits the nozzle MAWP.

UG-37 Area Calculation Summary (cm^2) For P = 1,580 kPa @ 150 °C							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}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							4.76	4.8

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	1.74	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	2.56	5.6	weld size is adequate
Nozzle to pad groove (Upper)	1.74	9	weld size is adequate

Calculations for internal pressure 1,580 kPa @ 150 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt per UCS-66(d) (NPS 4 or smaller pipe).

Pad is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.3441).

Nozzle UCS-66 governing thk:	4.8 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	8.11 mm
Pad rated MDMT:	-105 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(83.93, 41.96 + (5.49 - 3) + (8.11 - 3))$$
$$= 83.93 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(8.11 - 3), 2.5*(5.49 - 3) + 9)$$
$$= 12.78 \text{ mm}$$

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 1,580.0016*41.96 / (118,000*1 - 0.6*1,580.0016)
= 0.57 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 1,580.0016*130.26 / (118,000*1 - 0.6*1,580.0016)
= 1.76 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 2.49 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 1.74 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 5.11 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 2.56 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,580.0016*41.96 / (118,000*1 - 0.6*1,580.0016) + 3
= 3.57 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[3.57 , 0]
= 3.57 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 1,580.0016*130.26 / (118,000*1 - 0.6*1,580.0016) + 3
= 4.76 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.76 , 4.5]
= 4.76 mm

t_b = min[t_{b3} , t_{b1}]
= min[7.8 , 4.76]
= 4.76 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[3.57 , 4.76]

$= \quad 4.76\ mm$

Available nozzle wall thickness new, t_n = 0.875*5.49 = 4.8 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The attached ASME B16.5 flange limits the nozzle MAP.

UG-37 Area Calculation Summary (cm^2) For P = 1,960 kPa @ 21.11 °C							**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}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							2.14	4.8

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

UW-16 Weld Sizing Summary			
Weld description	**Required weld size (mm)**	**Actual weld size (mm)**	**Status**
Nozzle to pad fillet (Leg_{41})	3.84	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	4.06	5.6	weld size is adequate
Nozzle to pad groove (Upper)	3.84	9	weld size is adequate

Calculations for internal pressure 1,960 kPa @ 21.11 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(77.93, 38.96 + (5.49 - 0) + (8.11 - 0))
= 77.93 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*(8.11 - 0), 2.5*(5.49 - 0) + 9)
= 20.28 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,960.002*38.96 / (118,000*1 - 0.6*1,960.002)
= 0.65 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 1,960.002*127.26 / (118,000*1 - 0.6*1,960.002)
= 2.14 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 5.49 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 3.84 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 8.11 mm
$t_{w(min)}$ = 0.5*t_{min} = 4.06 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,960.002*38.96 / (118,000*1 - 0.6*1,960.002) + 0
= 0.65 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.65 , 0]
= 0.65 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 1,960.002*127.26 / (118,000*1 - 0.6*1,960.002) + 0
= 2.14 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[2.14 , 1.5]
= 2.14 mm

t_b = min[t_{b3} , t_{b1}]
= min[4.8 , 2.14]
= 2.14 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.65 , 2.14]
= 2.14 mm

Available nozzle wall thickness new, t_n = 0.875*5.49 = 4.8 mm

The nozzle neck thickness is adequate.

TS Outlet (N2)

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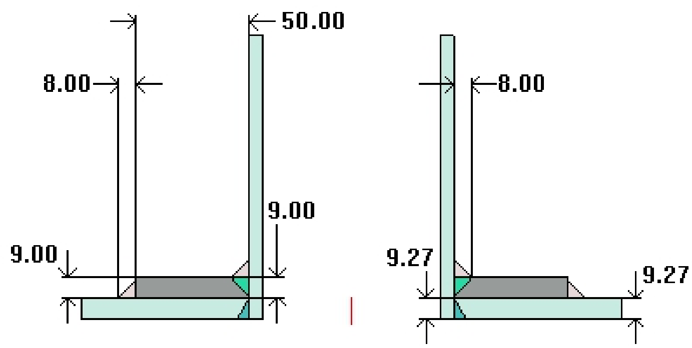

$t_{w(lower)}$ = 9.27 mm
Leg_{41} = 8 mm
$t_{w(upper)}$ = 9 mm
Leg_{42} = 8 mm
D_p = 188.9 mm
t_e = 9 mm

.

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

Located on:	Front Channel
Liquid static head included:	0 kPa
Nozzle material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	NPS 3 Sch 40 (Std) DN 80
Pad material specification:	SA-516 70 (II-D Metric p. 18, ln. 19)
Pad diameter:	188.9 mm
Flange description:	NPS 3 Class 150 WN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Flange rated MDMT:	-39.89°C
(UCS-66(b)(1)(b))	
Liquid static head on flange:	0 kPa
ASME B16.5-2009 flange rating MAWP:	1,580 kPa @ 150°C
ASME B16.5-2009 flange rating MAP:	1,960 kPa @ 21.11°C
ASME B16.5-2009 flange hydro test:	3,000 kPa @ 21.11°C
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1
Nozzle orientation:	180°
Local vessel minimum thickness:	8.11 mm
Nozzle center line offset to datum line:	2,128.4 mm
End of nozzle to shell center:	288.93 mm
Nozzle inside diameter, new:	77.93 mm
Nozzle nominal wall thickness:	5.49 mm
Nozzle corrosion allowance:	3 mm
Projection available outside vessel, Lpr:	82.55 mm
Projection available outside vessel to flange face, Lf:	152.4 mm
Pad is split:	No

Reinforcement Calculations for Internal Pressure

The attached ASME B16.5 flange limits the nozzle MAWP.

UG-37 Area Calculation Summary (cm^2) For P = 1,580 kPa @ 150 °C							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}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							4.76	4.8

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	1.74	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	2.56	5.6	weld size is adequate
Nozzle to pad groove (Upper)	1.74	9	weld size is adequate

Calculations for internal pressure 1,580 kPa @ 150 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt per UCS-66(d) (NPS 4 or smaller pipe).

Pad is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.3441).

Nozzle UCS-66 governing thk:	4.8 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	8.11 mm
Pad rated MDMT:	-105 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(83.93, 41.96 + (5.49 - 3) + (8.11 - 3))$$
$$= 83.93 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(8.11 - 3), 2.5*(5.49 - 3) + 9)$$
$$= 12.78 \text{ mm}$$

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 1,580.0016*41.96 / (118,000*1 - 0.6*1,580.0016)
= 0.57 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 1,580.0016*130.26 / (118,000*1 - 0.6*1,580.0016)
= 1.76 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 2.49 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 1.74 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 5.11 mm
$t_{w(min)}$ = 0.5*t_{min} = 2.56 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,580.0016*41.96 / (118,000*1 - 0.6*1,580.0016) + 3
= 3.57 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[3.57 , 0]
= 3.57 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 1,580.0016*130.26 / (118,000*1 - 0.6*1,580.0016) + 3
= 4.76 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.76 , 4.5]
= 4.76 mm

t_b = min[t_{b3} , t_{b1}]
= min[7.8 , 4.76]
= 4.76 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[3.57 , 4.76]

$= \quad 4.76 \text{ mm}$

Available nozzle wall thickness new, t_n = 0.875*5.49 = 4.8 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The attached ASME B16.5 flange limits the nozzle MAP.

UG-37 Area Calculation Summary (cm^2) For P = 1,960 kPa @ 21.11 °C							**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}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							2.14	4.8

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

UW-16 Weld Sizing Summary			
Weld description	**Required weld size (mm)**	**Actual weld size (mm)**	**Status**
Nozzle to pad fillet (Leg_{41})	3.84	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	4.06	5.6	weld size is adequate
Nozzle to pad groove (Upper)	3.84	9	weld size is adequate

Calculations for internal pressure 1,960 kPa @ 21.11 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(77.93, 38.96 + (5.49 - 0) + (8.11 - 0))
= 77.93 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*(8.11 - 0), 2.5*(5.49 - 0) + 9)
= 20.28 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,960.002*38.96 / (118,000*1 - 0.6*1,960.002)
= 0.65 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 1,960.002*127.26 / (118,000*1 - 0.6*1,960.002)
= 2.14 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 5.49 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 3.84 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 8.11 mm
$t_{w(min)}$ = 0.5*t_{min} = 4.06 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,960.002*38.96 / (118,000*1 - 0.6*1,960.002) + 0
= 0.65 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.65 , 0]
= 0.65 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 1,960.002*127.26 / (118,000*1 - 0.6*1,960.002) + 0
= 2.14 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[2.14 , 1.5]
= 2.14 mm

t_b = min[t_{b3} , t_{b1}]
= min[4.8 , 2.14]
= 2.14 mm

t_{UG-45} = max[t_a , t_b]
= max[0.65 , 2.14]
= 2.14 mm

Available nozzle wall thickness new, t_n = 0.875*5.49 = 4.8 mm

The nozzle neck thickness is adequate.

SS Inlet (N3)

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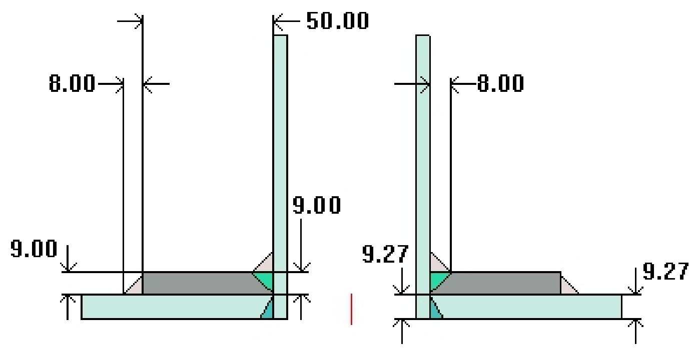

$t_{w(lower)}$ = 9.27 mm
Leg_{41} = 8 mm
$t_{w(upper)}$ = 9 mm
Leg_{42} = 8 mm
D_p = 160.33 mm
t_e = 9 mm

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

Located on:	Shell
Liquid static head included:	0 kPa
Nozzle material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	NPS 2 Sch 80 (XS) DN 50
Pad material specification:	SA-516 70 (II-D Metric p. 18, ln. 19)
Pad diameter:	160.33 mm
Flange description:	NPS 2 Class 150 WN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Flange rated MDMT:	-48°C
(UCS-66(b)(1)(b))	
Liquid static head on flange:	0 kPa
ASME B16.5-2009 flange rating MAWP:	1,875 kPa @ 65°C
ASME B16.5-2009 flange rating MAP:	1,960 kPa @ 21.11°C
ASME B16.5-2009 flange hydro test:	3,000 kPa @ 21.11°C
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1
Nozzle orientation:	180°
Local vessel minimum thickness:	8.11 mm
Nozzle center line offset to datum line:	1,642.44 mm
End of nozzle to shell center:	288.93 mm
Nozzle inside diameter, new:	49.25 mm
Nozzle nominal wall thickness:	5.54 mm
Nozzle corrosion allowance:	3 mm
Projection available outside vessel, Lpr:	88.9 mm
Projection available outside vessel to flange face, Lf:	152.4 mm
Pad is split:	No

Reinforcement Calculations for Internal Pressure

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

<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (cm^2)
For P = 1,657.56 kPa @ 65 °C</th><th colspan="2">UG-45 Nozzle Wall Thickness Summary (mm)
The nozzle passes UG-45</th></tr>
<tr><th>A required</th><th>A available</th><th>A_1</th><th>A_2</th><th>A_3</th><th>A_5</th><th>A welds</th><th>t_{req}</th><th>t_{min}</th></tr>
<tr><td colspan="7">This nozzle is exempt from area calculations per UG-36(c)(3)(a)</td><td>4.84</td><td>4.85</td></tr>
</table>

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

UW-16 Weld Sizing Summary			
Weld description	**Required weld size (mm)**	**Actual weld size (mm)**	**Status**
Nozzle to pad fillet (Leg_{41})	1.78	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	2.56	5.6	weld size is adequate
Nozzle to pad groove (Upper)	1.78	9	weld size is adequate

Calculations for internal pressure 1,657.56 kPa @ 65 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt per UCS-66(d) (NPS 4 or smaller pipe).

Pad is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2389).

Nozzle UCS-66 governing thk:	4.85 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	8.11 mm
Pad rated MDMT:	-105 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, $R_n + (t_n - C_n) + (t - C)$)
= MAX(55.25, 27.63 + (5.54 - 3) + (8.11 - 3))
= 55.25 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*(8.11 - 3), 2.5*(5.54 - 3) + 9)
= 12.78 mm

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 1,657.5585*27.63 / (118,000*1 - 0.6*1,657.5585)
= 0.39 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 1,657.5585*130.26 / (118,000*1 - 0.6*1,657.5585)
= 1.85 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 2.54 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 1.78 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 5.11 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 2.56 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,657.5585*27.63 / (118,000*1 - 0.6*1,657.5585) + 3
= 3.39 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[3.39 , 0]
= 3.39 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 1,657.5585*130.26 / (118,000*1 - 0.6*1,657.5585) + 3
= 4.84 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.84 , 4.5]
= 4.84 mm

t_b = min[t_{b3} , t_{b1}]
= min[6.42 , 4.84]
= 4.84 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[3.39 , 4.84]

$= 4.84$ mm

Available nozzle wall thickness new, t_n = 0.875*5.54 = 4.85 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The attached ASME B16.5 flange limits the nozzle MAP.

UG-37 Area Calculation Summary (cm²) For P = 1,960 kPa @ 21.11 °C							**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}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							2.14	4.85

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

UW-16 Weld Sizing Summary			
Weld description	**Required weld size (mm)**	**Actual weld size (mm)**	**Status**
Nozzle to pad fillet (Leg_{41})	3.88	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	4.06	5.6	weld size is adequate
Nozzle to pad groove (Upper)	3.88	9	weld size is adequate

Calculations for internal pressure 1,960 kPa @ 21.11 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(49.25, 24.63 + (5.54 - 0) + (8.11 - 0))
= 49.25 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*(8.11 - 0), 2.5*(5.54 - 0) + 9)
= 20.28 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,960.002*24.63 / (118,000*1 - 0.6*1,960.002)
= 0.41 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 1,960.002*127.26 / (118,000*1 - 0.6*1,960.002)
= 2.14 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 5.54 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 3.88 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 8.11 mm
$t_{w(min)}$ = 0.5*t_{min} = 4.06 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,960.002*24.63 / (118,000*1 - 0.6*1,960.002) + 0
= 0.41 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.41 , 0]
= 0.41 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 1,960.002*127.26 / (118,000*1 - 0.6*1,960.002) + 0
= 2.14 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[2.14 , 1.5]
= 2.14 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 2.14]
= 2.14 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.41 , 2.14]
= 2.14 mm

Available nozzle wall thickness new, t_n = 0.875*5.54 = 4.85 mm

The nozzle neck thickness is adequate.

SS Outlet (N4)

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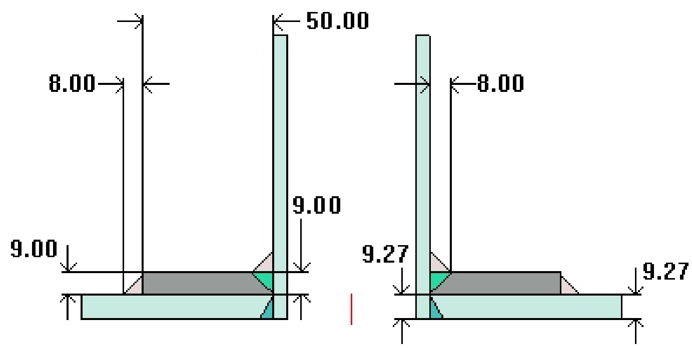


$t_{w(lower)}$ = 9.27 mm
Leg_{41} = 8 mm
$t_{w(upper)}$ = 9 mm
Leg_{42} = 8 mm
D_p = 160.33 mm
t_e = 9 mm

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

Located on:	Shell
Liquid static head included:	0 kPa
Nozzle material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	NPS 2 Sch 80 (XS) DN 50
Pad material specification:	SA-516 70 (II-D Metric p. 18, ln. 19)
Pad diameter:	160.33 mm
Flange description:	NPS 2 Class 150 WN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Flange rated MDMT:	-48°C
(UCS-66(b)(1)(b))	
Liquid static head on flange:	0 kPa
ASME B16.5-2009 flange rating MAWP:	1,875 kPa @ 65°C
ASME B16.5-2009 flange rating MAP:	1,960 kPa @ 21.11°C
ASME B16.5-2009 flange hydro test:	3,000 kPa @ 21.11°C
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1
Nozzle orientation:	0°
Local vessel minimum thickness:	8.11 mm
Nozzle center line offset to datum line:	80.96 mm
End of nozzle to shell center:	288.93 mm
Nozzle inside diameter, new:	49.25 mm
Nozzle nominal wall thickness:	5.54 mm
Nozzle corrosion allowance:	3 mm
Projection available outside vessel, Lpr:	88.9 mm
Projection available outside vessel to flange face, Lf:	152.4 mm
Pad is split:	No

Reinforcement Calculations for Internal Pressure

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

UG-37 Area Calculation Summary (cm^2) For P = 1,657.56 kPa @ 65 °C							**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}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							4.84	4.85

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

UW-16 Weld Sizing Summary			
Weld description	**Required weld size (mm)**	**Actual weld size (mm)**	**Status**
Nozzle to pad fillet (Leg_{41})	1.78	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	2.56	5.6	weld size is adequate
Nozzle to pad groove (Upper)	1.78	9	weld size is adequate

Calculations for internal pressure 1,657.56 kPa @ 65 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt per UCS-66(d) (NPS 4 or smaller pipe).

Pad is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2389).

Nozzle UCS-66 governing thk:	4.85 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	8.11 mm
Pad rated MDMT:	-105 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(55.25, 27.63 + (5.54 - 3) + (8.11 - 3))
= 55.25 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*(8.11 - 3), 2.5*(5.54 - 3) + 9)
= 12.78 mm

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 1,657.5585*27.63 / (118,000*1 - 0.6*1,657.5585)
= 0.39 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 1,657.5585*130.26 / (118,000*1 - 0.6*1,657.5585)
= 1.85 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 2.54 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 1.78 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 5.11 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 2.56 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,657.5585*27.63 / (118,000*1 - 0.6*1,657.5585) + 3
= 3.39 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[3.39 , 0]
= 3.39 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 1,657.5585*130.26 / (118,000*1 - 0.6*1,657.5585) + 3
= 4.84 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.84 , 4.5]
= 4.84 mm

t_b = min[t_{b3} , t_{b1}]
= min[6.42 , 4.84]
= 4.84 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[3.39 , 4.84]

= 4.84 mm

Available nozzle wall thickness new, t_n = 0.875*5.54 = 4.85 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The attached ASME B16.5 flange limits the nozzle MAP.

UG-37 Area Calculation Summary (cm^2) For P = 1,960 kPa @ 21.11 °C							**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}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							2.14	4.85

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

UW-16 Weld Sizing Summary			
Weld description	**Required weld size (mm)**	**Actual weld size (mm)**	**Status**
Nozzle to pad fillet (Leg_{41})	3.88	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	4.06	5.6	weld size is adequate
Nozzle to pad groove (Upper)	3.88	9	weld size is adequate

Calculations for internal pressure 1,960 kPa @ 21.11 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(49.25, 24.63 + (5.54 - 0) + (8.11 - 0))
= 49.25 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*(8.11 - 0), 2.5*(5.54 - 0) + 9)
= 20.28 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,960.002*24.63 / (118,000*1 - 0.6*1,960.002)
= 0.41 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 1,960.002*127.26 / (118,000*1 - 0.6*1,960.002)
= 2.14 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 5.54 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 3.88 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 8.11 mm
$t_{w(min)}$ = 0.5*t_{min} = 4.06 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,960.002*24.63 / (118,000*1 - 0.6*1,960.002) + 0
= 0.41 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.41 , 0]
= 0.41 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 1,960.002*127.26 / (118,000*1 - 0.6*1,960.002) + 0
= 2.14 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[2.14 , 1.5]
= 2.14 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 2.14]
= 2.14 mm

t_{UG-45} = max[t_a , t_b]
= max[0.41 , 2.14]
= 2.14 mm

Available nozzle wall thickness new, t_n = 0.875*5.54 = 4.85 mm

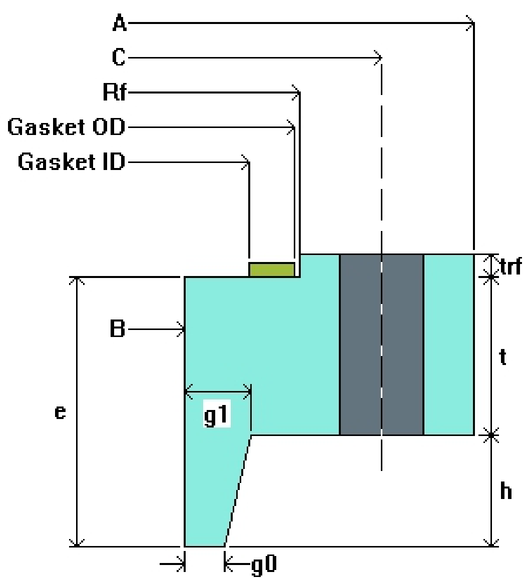
The nozzle neck thickness is adequate.

Shell Side Flange (front)

ASME VIII-1, 2010 Edition, A11 Addenda Metric, Appendix 2 Flange Calculations

Flange is attached to:	Shell (Left)	
Flange type:	Weld neck integral	
Flange material specification:	SA-266 2 (II-D Metric p. 18, ln. 8)	
Bolt material specification:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)	
Bolt Description:	0.75 in Coarse Thread	
Internal design pressure, P:	1,100 kPa @ 65 °C	
Required flange thickness: t_r=	34.42 mm	
Maximum allowable working pressure, MAWP:	3,598.19 kPa @ 65 °C	
Maximum allowable pressure, MAP:	4,612.83 kPa @ 21.1111 °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:	-48 °C	Flange material is not normalized Material is produced to fine grain practice PWHT is not performed
Estimated weight:	New = 22.36 kg	corroded = 21.18 kg

Flange dimensions, new



flange OD	A	= 386 mm
bolt circle	C	= 344 mm
raised face ID	Rf	= 307 mm
gasket OD		= 304 mm
gasket ID		= 284 mm
flange ID	B	= 254.51 mm
facing height	t_{rf}	= 5 mm
thickness	t	= 36 mm
bolting		= 16- 0.75 in dia
hub thickness	g_1	= 15.25 mm
hub thickness	g_0	= 9.27 mm
hub length	h	= 25 mm
length	e	= 61 mm
gasket factor	m	= 4
seating stress	y	= 69 MPa

Gasket thickness T = 3.2 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 to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2385)
Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C

The rated flange MDMT is -48 °C

Flange calculations for Internal Pressure + Weight Only

Gasket details from facing sketch Confined gasket 1(a), Column I

Gasket width N = 10 mm

b_0 = N/2 = 5 mm

Effective gasket seating width, b = b_0 = 5 mm

G = (OD of contact face + gasket ID) / 2 = (304 + 284) / 2 = 294 mm

h_G = (C - G)/2 = (344 - 294)/2 = 25 mm

h_D = R + g_1/2 = 29.5 + 12.25/2 = 35.62 mm

h_T = (R + g_1 + h_G)/2 = (29.5 + 12.25 + 25)/2 = 33.37 mm

H_p = 2*b*3.14*G*m*P
= 2*5*3.14*294*4*1.1
= 40,619.05 N

H = 0.785*G^2*P
= 0.785*294^2*1.1
= 74,637.5 N

H_D = 0.785*B^2*P
= 0.785*260.51^2*1.1
= 58,601.6 N

H_T = H - H_D
= 74,637.5 - 58,601.6
= 16,035.9 N

W_{m1} = H + H_p
= 74,637.5 + 40,619.05
= 115,256.54 N

W_{m2} = 3.14*b*G*y
= 3.14*5*294*69
= 318,490.24 N

Per VIII-1, Appendix 2-5(a)(2): W_{m2} from the mating flange governs so W_{m2} = 494,102.16 N

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 28.7269 cm^2

A_{m1} = W_{m1}/S_b = 115,256.54/(100*172) = 6.701 cm^2

A_{m2} = W_{m2}/S_a = 494,102.16/(100*172) = 28.7269 cm^2

Total area for 16- 0.75 in dia bolts, corroded, A_b = 31.1741 cm^2

W = (A_m + A_b)*S_a/2
= (2,872.6866 + 3,117.413)*172/2
= 515,148.64 N

M_D = H_D*h_D = 58,601.6*0.0356 = 2,087.4 N-m
M_T = H_T*h_T = 16,035.9*0.0334 = 535.2 N-m

$H_G = W_{m1} - H = 115{,}256.54 - 74{,}637.5 = 40{,}619.05$ N

$M_G = H_G*h_G = 40{,}619.05*0.025 = 1{,}015.5$ N-m

$M_o = M_D + M_T + M_G = 2{,}087.4 + 535.2 + 1{,}015.5 = 3{,}638$ N-m

$M_g = W*h_G = 515{,}148.64*0.025 = 12{,}878.7$ N-m

The bolts are adequately spaced so the TEMA RCB-11.23 load concentration factor does not apply.

Hub and Flange Factors

$h_0 = (B*g_0)^{1/2} = (260.51*5.11)^{1/2} = 36.49$ mm

From FIG. 2-7.1, where K = A/B = 386/260.51 = 1.4817

T = 1.7186	Z = 2.673	Y = 5.1095	U = 5.6148
$h/h_0 = 0.6851$	$g_1/g_0 = 2.3967$		
F = 0.773	V = 0.1503	$e = F/h_0 = 0.2118$	

$d = (U/V)*h_0*g_0^2 = (5.6148/0.1503)*3.649*0.5111^2$
$= 35.6177$ cm^3

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

f = 1.0768

$L = (t*e + 1)/T + t^3/d$
$= (3.6*0.2118 + 1)/1.7186 + 3.6^3/35.6177$
$= 2.3355$

$S_H = f*M_o/(L*g_1^2*B)$
$= 1e3*1.0768*3{,}638/(2.3355*12.25^2*260.51)$
$= 42.907$ MPa

$S_R = (1.33*t*e + 1)*M_o/(L*t^2*B)$
$= (1.33*36*0.0212 + 1)*1e3*3{,}638/(2.3355*36^2*260.51)$
$= 9.293$ MPa

$S_T = Y*M_o/(t^2*B) - Z*S_R$
$= 1e3*5.1095*3{,}638/(36^2*260.51) - 2.673*9.293$
$= 30.217$ MPa

Allowable stress $S_{fo} = 138$ MPa
Allowable stress $S_{no} = 118$ 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}
$0.5(S_H + S_R) = 26.1$ MPa does not exceed S_{fo}
$0.5(S_H + S_T) = 36.562$ MPa does not exceed S_{fo}

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

$S_H = f*M_g/(L*g_1^2*B)$
$= 1e3*1.0768*12{,}878.7/(2.3355*12.25^2*260.51)$
$= 151.89$ MPa

$S_R = (1.33*t*e + 1)*M_g/(L*t^2*B)$
$= (1.33*36*0.0212 + 1)*1e3*12{,}878.7/(2.3355*36^2*260.51)$
$= 32.899$ MPa

$S_T = Y*M_g/(t^2*B) - Z*S_R$
$= 5.1095*1e3*12{,}878.7/(36^2*260.51) - 2.673*32.899$
$= 106.967$ MPa

Allowable stress S_{fa} = 138 MPa
Allowable stress S_{na} = 118 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}
$0.5(S_H + S_R)$ = 92.394 MPa does not exceed S_{fa}
$0.5(S_H + S_T)$ = 129.429 MPa does not exceed S_{fa}

Flange rigidity per VIII-1, Appendix 2-14

$J = 52.14*V*M_o/(L*E*g_0^2*K_l*h_0)$
$= 1e3*52.14*0.1503*12{,}878.7/(2.3355*202.27E{+}03*5.11^2*0.3*36.49)$
$= 0.7469$

The flange rigidity index J does not exceed 1; satisfactory.

Shell Side Flange (front) - Flange hub

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric

Component:	Flange hub
Material specification:	SA-266 2 (II-D Metric p. 18, ln. 8)

Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.1664)

Internal design pressure: P = 1,100 kPa @ 65 °C

Static liquid head:

P_{th} = 4.08 kPa (SG = 1, H_s = 416.18 mm, Horizontal test head)

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

Design MDMT = -29 °C	No impact test performed
Rated MDMT = -105 °C	Material is not 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 = 1.5 kg	corr = 1 kg
Capacity	New = 1.27 liters	corr = 1.33 liters

ID = 254.51 mm
= 25 mm

Length
L_c
t = 9.27 mm

Design thickness, (at 65 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 1,100*130.25 / (138,000*1.00 - 0.60*1,100) + 3
= 4.04 mm

Maximum allowable working pressure, (at 65 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*6.27 / (130.25 + 0.60*6.27) - 0
= 6,456.62 kPa

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*9.27 / (127.26 + 0.60*9.27)
= 9,631.75 kPa

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

A = 0.125 / (R_o / t)
= 0.125 / (136.53 / 6.27)
= 0.005741
B = 119.17 MPa
S = 138 / 1.00 = 138 MPa
S_{cHC} = min(B, S) = 119.17 MPa

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

A = 0.125 / (R_o / t)
= 0.125 / (136.53 / 9.27)
= 0.008487
B = 119.65 MPa
S = 138 / 1.00 = 138 MPa
S_{cHN} = min(B, S) = 119.65 MPa

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

A = 0.125 / (R_o / t)
= 0.125 / (136.53 / 9.27)
= 0.008487
B = 119.65 MPa
S = 138 / 1.00 = 138 MPa
S_{cCN} = min(B, S) = 119.65 MPa

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

A	=	0.125 / (R_o / t)
	=	0.125 / (136.53 / 6.27)
	=	0.005741
B	=	119.17 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCC}	=	min(B, S) = 119.17 MPa

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

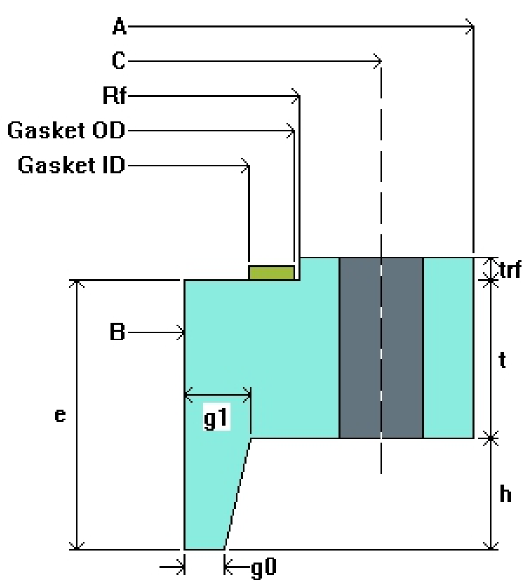
A	=	0.125 / (R_o / t)
	=	0.125 / (136.53 / 6.27)
	=	0.005741
B	=	119.17 MPa
S	=	138 / 1.00 = 138 MPa
S_{cVC}	=	min(B, S) = 119.17 MPa

Tube Side Flange (front)

ASME VIII-1, 2010 Edition, A11 Addenda Metric, Appendix 2 Flange Calculations

Flange is attached to:	Front Channel (Right)	
Flange type:	Weld neck integral	
Flange material specification:	SA-266 2 (II-D Metric p. 18, ln. 8)	
Bolt material specification:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)	
Bolt Description:	0.75 in Coarse Thread	
Internal design pressure, P:	750 kPa @ 150 °C	
Required flange thickness: t_r=	34.42 mm	
Maximum allowable working pressure, MAWP:	3,598.11 kPa @ 150 °C	
Maximum allowable pressure, MAP:	4,284.78 kPa @ 21.1111 °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:	-48 °C	Flange material is not normalized Material is produced to fine grain practice PWHT is not performed
Estimated weight:	New = 22.36 kg	corroded = 21.18 kg

Flange dimensions, new



flange OD	A	= 386 mm
bolt circle	C	= 344 mm
raised face ID	Rf	= 307 mm
gasket OD		= 304 mm
gasket ID		= 284 mm
flange ID	B	= 254.51 mm
facing height	t_{rf}	= 5 mm
thickness	t	= 36 mm
bolting		= 16- 0.75 in dia
hub thickness	g_1	= 15.25 mm
hub thickness	g_0	= 9.27 mm
hub length	h	= 25 mm
length	e	= 61 mm
gasket factor	m	= 4
seating stress	y	= 69 MPa

Gasket thickness T = 3.2 mm

Note: this flange is calculated as an integral type.

Determination of Flange MDMT

UCS-66(b)(1)(b) has been applied.
Flange impact test exemption temperature from Fig UCS-66M Curve B = -29 °C
Fig UCS-66.1M MDMT reduction = 65.8 °C, (coincident ratio = 0.3687)
Rated MDMT of -94.8°C is limited to -48°C by UCS-66(b)(2)
UCS-66 governing thickness = 8.11 mm
Bolts rated MDMT per Fig UCS-66 note (c) = -48 °C

The rated flange MDMT is -48 °C

Flange calculations for Internal Pressure + Weight Only

Gasket details from facing sketch Confined gasket 1(a), Column I

Gasket width N = 10 mm

b_0 = N/2 = 5 mm

Effective gasket seating width, b = b_0 = 5 mm

G = (OD of contact face + gasket ID) / 2 = (304 + 284) / 2 = 294 mm

h_G = (C - G)/2 = (344 - 294)/2 = 25 mm

h_D = R + g_1/2 = 29.5 + 12.25/2 = 35.62 mm

h_T = (R + g_1 + h_G)/2 = (29.5 + 12.25 + 25)/2 = 33.37 mm

H_p = 2*P*(b*3.14*G*m + b_r*r_l*m')
= 2*0.75*(5*3.14*294*4 + 10*254.51*4)
= 42,965.41 N

H = 0.785*G^2*P
= 0.785*294^2*0.75
= 50,889.2 N

H_D = 0.785*B^2*P
= 0.785*260.51^2*0.75
= 39,955.64 N

H_T = H - H_D
= 50,889.2 - 39,955.64
= 10,933.57 N

W_{m1} = H + H_p
= 50,889.2 + 42,965.41
= 93,854.61 N

Per VIII-1, Appendix 2-5(a)(2): W_{m1} from the mating flange governs so W_{m1} = 115,256.54 N

W_{m2} = 3.14*b*G*y + b_r*r_l*Y'
= 3.14*5*294*69 + 10*254.51*69
= 494,102.16 N

The pass partition gasket load has been included in the calculation of W_{m1} and W_{m2} per TEMA RGP-RCB-11.7.

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 28.7269 cm^2

A_{m1} = W_{m1}/S_b = 115,256.54/(100*172) = 6.701 cm^2

A_{m2} = W_{m2}/S_a = 494,102.16/(100*172) = 28.7269 cm^2

Total area for 16- 0.75 in dia bolts, corroded, A_b = 31.1741 cm^2

W = (A_m + A_b)*S_a/2
= (2,872.6866 + 3,117.413)*172/2
= 515,148.64 N

M_D = H_D*h_D = 39,955.64*0.0356 = 1,423.2 N-m

$M_T = H_T*h_T = 10,933.57*0.0334 = 364.9$ N-m

$H_G = W_{m1} - H = 115,256.54 - 50,889.2 = 64,367.34$ N

$M_G = H_G*h_G = 64,367.34*0.025 = 1,609.2$ N-m

$M_o = M_D + M_T + M_G = 1,423.2 + 364.9 + 1,609.2 = 3,397.3$ N-m

$M_g = W*h_G = 515,148.64*0.025 = 12,878.7$ N-m

The bolts are adequately spaced so the TEMA RCB-11.23 load concentration factor does not apply.

Hub and Flange Factors

$h_0 = (B*g_0)^{1/2} = (260.51*5.11)^{1/2} = 36.49$ mm

From FIG. 2-7.1, where K = A/B = 386/260.51 = 1.4817

T = 1.7186	Z = 2.673	Y = 5.1095	U = 5.6148
$h/h_0 = 0.6851$	$g_1/g_0 = 2.3967$		
F = 0.773	V = 0.1503	$e = F/h_0 = 0.2118$	

$d = (U/V)*h_0*g_0^2 = (5.6148/0.1503)*3.649*0.5111^2$
$= 35.6177$ cm^3

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

f = 1.0768

$L = (t*e + 1)/T + t^3/d$
$= (3.6*0.2118 + 1)/1.7186 + 3.6^3/35.6177$
$= 2.3355$

$S_H = f*M_o/(L*g_1^2*B)$
$= 1e3*1.0768*3,397.3/(2.3355*12.25^2*260.51)$
= 40.067 MPa

$S_R = (1.33*t*e + 1)*M_o/(L*t^2*B)$
$= (1.33*36*0.0212 + 1)*1e3*3,397.3/(2.3355*36^2*260.51)$
= 8.678 MPa

$S_T = Y*M_o/(t^2*B) - Z*S_R$
$= 1e3*5.1095*3,397.3/(36^2*260.51) - 2.673*8.678$
= 28.217 MPa

Allowable stress S_{fo} = 138 MPa
Allowable stress S_{no} = 118 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}
$0.5(S_H + S_R)$ = 24.373 MPa does not exceed S_{fo}
$0.5(S_H + S_T)$ = 34.142 MPa does not exceed S_{fo}

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

$S_H = f*M_g/(L*g_1^2*B)$

= 1e3*1.0768*12,878.7/(2.3355*12.25^2*260.51)
= 151.89 MPa

S_R = (1.33*t*e + 1)*M_g/(L*t^2*B)
= (1.33*36*0.0212 + 1)*1e3*12,878.7/(2.3355*36^2*260.51)
= 32.899 MPa

S_T = Y*M_g/(t^2*B) - Z*S_R
= 5.1095*1e3*12,878.7/(36^2*260.51) - 2.673*32.899
= 106.967 MPa

Allowable stress S_{fa} = 138 MPa
Allowable stress S_{na} = 118 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) = 92.394 MPa does not exceed S_{fa}
0.5(S_H + S_T) = 129.429 MPa does not exceed S_{fa}

Flange rigidity per VIII-1, Appendix 2-14

J = 52.14*V*M_o/(L*E*g_0^{2}*K_I*h_0)
= 1e3*52.14*0.1503*12,878.7/(2.3355*202.27E+03*5.11^2*0.3*36.49)
= 0.7469

The flange rigidity index J does not exceed 1; satisfactory.

Tube Side Flange (front) - Flange hub

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric

Component:	Flange hub
Material specification:	SA-266 2 (II-D Metric p. 18, ln. 8)

Material is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2395)

Internal design pressure: P = 750 kPa @ 150 °C

Static liquid head:

P_{th} = 4.08 kPa (SG = 1, H_s = 416.18 mm, Horizontal test head)

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

Design MDMT = -29 °C	No impact test performed
Rated MDMT = -105 °C	Material is not 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 = 1.5 kg	corr = 1 kg
Capacity	New = 1.27 liters	corr = 1.33 liters

ID	=	254.51 mm
Length L_c	=	25 mm
t	=	9.27 mm

Design thickness, (at 150 °C) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 750*130.25 / (138,000*1.00 - 0.60*750) + 3
= 3.71 mm

Maximum allowable working pressure, (at 150 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 138,000*1.00*6.27 / (130.25 + 0.60*6.27) - 0
= 6,456.62 kPa

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 138,000*1.00*9.27 / (127.26 + 0.60*9.27)
= 9,631.75 kPa

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

A = 0.125 / (R_o / t)
= 0.125 / (136.53 / 6.27)
= 0.005741

B = 119.17 MPa

S = 138 / 1.00 = 138 MPa

S_{cHC} = min(B, S) = 119.17 MPa

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

A = 0.125 / (R_o / t)
= 0.125 / (136.53 / 9.27)
= 0.008487

B = 119.65 MPa

S = 138 / 1.00 = 138 MPa

S_{cHN} = min(B, S) = 119.65 MPa

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

A = 0.125 / (R_o / t)
= 0.125 / (136.53 / 9.27)
= 0.008487

B = 119.65 MPa

S = 138 / 1.00 = 138 MPa

S_{cCN} = min(B, S) = 119.65 MPa

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

A	=	$0.125 / (R_o / t)$
	=	0.125 / (136.53 / 6.27)
	=	0.005741
B	=	119.17 MPa
S	=	138 / 1.00 = 138 MPa
S_{cCC}	=	min(B, S) = 119.17 MPa

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

A	=	$0.125 / (R_o / t)$
	=	0.125 / (136.53 / 6.27)
	=	0.005741
B	=	119.17 MPa
S	=	138 / 1.00 = 138 MPa
S_{cVC}	=	min(B, S) = 119.17 MPa

Saddle

Saddle material:			A283 C
Saddle construction is:			Web at edge of rib
Saddle allowable stress:	S_s =	108	MPa
Saddle yield stress:	S_y =	205	MPa
Saddle distance to datum:		495	mm
Tangent to tangent length:	L =	2,419.8	mm
Saddle separation:	L_s =	952	mm
Vessel radius:	R =	136.53	mm
Tangent distance left:	A_l =	914.1	mm
Tangent distance right:	A_r =	553.7	mm
Tubesheet distance left:	A_{tsl} =	419.7	mm
Saddle height:	H_s =	400	mm
Saddle contact angle:	θ =	120	°
Wear plate thickness:	t_p =	8	mm
Wear plate width:	W_p =	200	mm
Wear plate contact angle:	θ_w =	144.8	°
Web plate thickness:	t_s =	6	mm
Base plate length:	E =	300	mm
Base plate width:	F =	150	mm
Base plate thickness:	t_b =	12	mm
Number of stiffener ribs:	n =	2	
Largest stiffener rib spacing:	d_i =	268.6	mm
Stiffener rib thickness:	t_w =	6	mm
Saddle width:	B =	150	mm
Anchor bolt size & type:			0.625 inch coarse threaded
Anchor bolt material:			SA-307 B
Anchor bolt allowable shear:		138	MPa
Anchor bolt corrosion allowance:		0	mm
Anchor bolts per saddle:		2	
Base coefficient of friction:	μ =	0.4	

Saddle mounted on a steel foundation.

Weight on left saddle:	operating corr =	292.11 kg,	test new =	429.55	kg
Weight on right saddle:	operating corr =	46.72 kg,	test new =	88	kg
Weight of saddle pair	=	32.66 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	14.189	118	0.049	118	33.858	118	19.717	118
Weight	Test	11.411	216.9	0.059	118	30.762	216.9	19.41	118

Load	Vessel condition	Tangential shear (MPa)		Circumferential stress (MPa)			Stress over saddle (MPa)		Splitting (MPa)	
		S_3	allow	S_4 (horns)	S_4 (Wear plate)	allow (+/-)	S_5	allow	S_6	allow
Weight	Operating	2.725	94.4	-2.808	-7.871	177	2.307	102.5	0.311	72
Weight	Test	2.475	173.52	-5.724	NA	216.9	2.511	184.5	0.458	184.5

Load Case 1: Weight ,Operating

Longitudinal stress between saddles (Weight ,Operating, right saddle loading and geometry govern)

S_1 = +- 3*K_1*Q*(L / 12) / (π*R^2*t)
= 3*0.0505*458.17*(2,419.8 / 12) / (π*133.97^2*5.11)
= 0.049 MPa

S_p = P*R / (2*t)
= 1.1*131.41 / (2*5.11)
= 14.141 MPa

Maximum tensile stress S_{1t} = S_1 + S_p = 14.189 MPa
Maximum compressive stress (shut down) S_{1c} = S_1 = 0.049 MPa

Tensile stress is acceptable (<=1*S*E = 118 MPa)
Compressive stress is acceptable (<=1*S_c = 118 MPa)

Longitudinal stress at the left saddle (Weight ,Operating)

L_e = 2*(Left head depth) / 3 + L + 2*(Right head depth) / 3
= 2*72.9 / 3 + 2,419.8 + 2*72.9 / 3
= 2,517 mm

w = W_t / L_e = 3,322.82*10 / 2,517 = 13.2 N/cm

Bending moment at the left saddle:

$M_q = w*(2*H*A_l / 3 + A_l^2 / 2 - (R^2 - H^2) / 4)$
$= 13.2 / 10000*(2*72.9*914.1 / 3 + 914.1^2 / 2 - (136.53^2 - 72.9^2) / 4)$
= 605.8 N-m

$S_2 = +- M_q*K_1' / (\pi*R^2*t)$
$= 605.8*1e3*9.3799 / (\pi*133.97^2*5.11)$
= 19.717 MPa

$S_p = P*R / (2*t)$
= 1.1*131.41 / (2*5.11)
= 14.141 MPa

Maximum tensile stress $S_{2t} = S_2 + S_p$ = 33.858 MPa
Maximum compressive stress (shut down) $S_{2c} = S_2$ = 19.717 MPa

Tensile stress is acceptable (<=1*S = 118 MPa)
Compressive stress is acceptable (<=1*S_c = 118 MPa)

Tangential shear stress in the shell (left saddle, Weight ,Operating)

$Q_{shear} = Q - w*(a + 2*H / 3)$
= 2,864.65 - 1.32*(914.1 + 2*72.9 / 3)
= 1,593.75 N

$S_3 = K_{2.2}*Q_{shear} / (R*t)$
= 1.1707*1,593.75 / (133.97*5.11)
= 2.725 MPa

Tangential shear stress is acceptable (<= 0.8*S = 94.4 MPa)

Circumferential stress at the left saddle horns (Weight ,Operating)

$S_4 = -Q / (4*(t+t_p)*(b+1.56*Sqr(R_o*t))) - 3*K_3*Q / (2*(t^2+t_p^2))$
$= -2,864.65 / (4*(5.11+8)*(150+1.56*Sqr(136.53*5.11))) - 3*0.0529*2,864.65 / (2*(5.11^2+8^2))$
= -2.808 MPa

Circumferential stress at saddle horns is acceptable (<=1.5*S_a = 177 MPa)

Circumferential stress at the left saddle wear plate horns (Weight ,Operating)

$S_4 = -Q / (4*t*(b+1.56*Sqr(R_o*t))) - 3*K_3*Q / (2*t^2)$
$= -2,864.65 / (4*5.11*(150+1.56*Sqr(136.53*5.11))) - 3*0.0434*2,864.65 / (2*5.11^2)$
= -7.871 MPa

Circumferential stress at wear plate horns is acceptable (<=1.5*S_a = 177 MPa)

Ring compression in shell over left saddle (Weight ,Operating)

$S_5 = K_5*Q / ((t + t_p)*(t_s + 1.56*Sqr(R_o*t_c)))$
= 0.7603*2,864.65 / ((5.11 + 8)*(6 + 1.56*Sqr(136.53*13.11)))
= 2.307 MPa

Ring compression in shell is acceptable (<= 0.5*S_y = 102.5 MPa)

Saddle splitting load (left, Weight ,Operating)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff}*t_s + t_p*W_p$
= 4.5508*0.6 + 0.8*20
= 18.7305 cm^2

$S_6 = K_8*Q / A_e$
= 0.2035*2,864.65 / 1,873.05
= 0.311 MPa

Stress in saddle is acceptable (<= (2 / 3)*S_s = 72 MPa)

Load Case 2: Weight ,Test

Longitudinal stress between saddles (Weight ,Test, right saddle loading and geometry govern)

S_1 = +- 3*K_1*Q*(L / 12) / (π*R^2*t)
= 3*0.0505*862.96*(2,419.8 / 12) / (π*132.47^2*8.11)
= 0.059 MPa

S_p = P*R / (2*t)
= 1.43*128.41 / (2*8.11)
= 11.352 MPa

Maximum tensile stress $S_{1t} = S_1 + S_p$ = 11.411 MPa
Maximum compressive stress (shut down) $S_{1c} = S_1$ = 0.059 MPa

Tensile stress is acceptable (<= 0.9*S_y = 216.9 MPa)
Compressive stress is acceptable (<=1*S_c = 118 MPa)

Longitudinal stress at the left saddle (Weight ,Test)

L_e = 2*(Left head depth) / 3 + L + 2*(Right head depth) / 3
= 2*72.9 / 3 + 2,419.8 + 2*72.9 / 3
= 2,517 mm

w = W_t / L_e = 5,075.42*10 / 2,517 = 20.16 N/cm

Bending moment at the left saddle:

M_q = w*(2*H*A_l / 3 + A_l^2 / 2 - (R^2 - H^2) / 4)
= 20.16 / 10000*(2*72.9*914.1 / 3 + 914.1^2 / 2 - (136.53^2 - 72.9^2) / 4)
= 925.3 N-m

S_2 = +- M_q*K_1' / (π*R^2*t)
= 925.3*1e3*9.3799 / (π*132.47^2*8.11)
= 19.41 MPa

S_p = P*R / (2*t)
= 1.43*128.41 / (2*8.11)
= 11.352 MPa

Maximum tensile stress $S_{2t} = S_2 + S_p$ = 30.762 MPa
Maximum compressive stress (shut down) $S_{2c} = S_2$ = 19.41 MPa

Tensile stress is acceptable (<= 0.9*S_y = 216.9 MPa)
Compressive stress is acceptable (<=1*S_c = 118 MPa)

Tangential shear stress in the shell (left saddle, Weight ,Test)

Q_{shear} = Q - w*(a + 2*H / 3)
= 4,212.47 - 2.02*(914.1 + 2*72.9 / 3)
= 2,271.22 N

$S_3 = K_{2.2}$*Q_{shear} / (R*t)
= 1.1707*2,271.22 / (132.47*8.11)
= 2.475 MPa

Tangential shear stress is acceptable (<= 0.8*(0.9*S_y) = 173.52 MPa)

Circumferential stress at the left saddle horns (Weight ,Test)

S_4 = -Q / (4*t*(b+1.56*Sqr(R_o*t))) - 3*K_3*Q / (2*t^2)
= -4,212.47 / (4*8.11*(150+1.56*Sqr(136.53*8.11))) - 3*0.0529*4,212.47 / (2*8.11^2)
= -5.724 MPa

Circumferential stress at saddle horns is acceptable (<= 0.9*S_y = 216.9 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*$(R_o t_c)^{0.5}$} =201.91 mm

Ring compression in shell over left saddle (Weight ,Test)

S_5 = K_5*Q / ((t + t_p)*(t_s + 1.56*Sqr(R_o*t_c)))
= 0.7603*4,212.47 / ((8.11 + 8)*(6 + 1.56*Sqr(136.53*16.11)))
= 2.511 MPa

Ring compression in shell is acceptable (<= 0.9*S_y = 184.5 MPa)

Saddle splitting load (left, Weight ,Test)

Area resisting splitting force = Web area + wear plate area

A_e = H_{eff}*t_s + t_p*W_p
= 4.5508*0.6 + 0.8*20
= 18.7305 cm^2

S_6 = K_8*Q / A_e
= 0.2035*4,212.47 / 1,873.05
= 0.458 MPa

Stress in saddle is acceptable (<= 0.9*S_y = 184.5 MPa)

Shear stress in anchor bolting, one end slotted

Maximum seismic or wind base shear = 0 N

Thermal expansion base shear = W*μ = 3,024.79*0.4 = 1,209.92 N
Corroded root area for a 0.625 inch coarse threaded bolt = 1.3032 cm^2 (2 per saddle)

Bolt shear stress = 1,209.92 / (130.3223*1*2) = 4.642 MPa

Anchor bolt stress is acceptable (<= 138 MPa)

Shear stress in anchor bolting, transverse

Maximum seismic or wind base shear = 0 N
Corroded root area for a 0.625 inch coarse threaded bolt = 1.3032 cm^2 (2 per saddle)

Bolt shear stress = 0 / (130.3223*2*2) = 0 MPa

Anchor bolt stress is acceptable (<= 138 MPa)

Web plate buckling check (Escoe pg 251)

Allowable compressive stress S_c is the lesser of 108 or 115.424 MPa: (108)

$S_c = K_i*\pi^2*E / (12*(1 - 0.3^2)*(d_i / t_s)^2)$
$= 1.28*\pi^2*199.95E+03 / (12*(1 - 0.3^2)*(268.6 / 6)^2)$
= 115.424 MPa

Allowable compressive load on the saddle

$b_e = d_i*t_s / (d_i*t_s + 2*t_w*(b - 25.4))*25.4$
= 268.6*6 / (268.6*6 + 2*6*(150 - 25.4))*25.4
= 13.18

$F_b = n*(A_s + 2*b_e*t_s)*S_c$
= 2*(864 + 2*13.18*6)*108
= 220,775.75 N

Saddle loading of 4,372.6 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*(400 - 112.91)*95.57 / (1e4*604.32) + 2,864.65 / 3,146.8094
= 0.91 MPa

The primary bending + axial stress in the saddle <= 108 MPa; satisfactory.

Secondary bending + axial stress in the saddle due to end loads (includes thermal expansion, assumes one saddle slotted)
$\sigma_b = V*(H_s - x_o)*y / I + Q / A$
= 1,209.92*(400 - 112.91)*95.57 / (1e4*604.32) + 2,864.65 / 3,146.8094
= 6.404 MPa

The secondary bending + axial stress in the saddle < $2*S_y$= 410 MPa; satisfactory.

Saddle base plate thickness check (Roark sixth edition, Table 26, case 7a)

where a = 268.6, b = 144 mm

$t_b = (\beta_1*q*b^2 / (1.5*S_a))^{0.5}$
$= (1.6633*0.097*144^2 / (1.5*108))^{0.5}$
= 4.55 mm

The base plate thickness of 12 mm is adequate.

Baffle Summary Report

Baffle Name	Distance from Front Tubesheet (mm)	Cut Direction	Cut Distance from Center (mm)	Baffle Weight (kg)[1]
Baffle #1	85.95	Upwards	64.39	2.2
Baffle #2	162.43	Downwards	64.39	2.2
Baffle #4	248.15	Upwards	64.39	2.2
Baffle #3	333.88	Downwards	64.39	2.2
Baffle #6	419.6	Upwards	64.39	2.2
Baffle #5	505.33	Downwards	64.39	2.2
Baffle #8	591.05	Upwards	64.39	2.2
Baffle #7	676.78	Downwards	64.39	2.2
Baffle #10	762.5	Upwards	64.39	2.2
Baffle #9	848.23	Downwards	64.39	2.2
Baffle #12	933.95	Upwards	64.39	2.2
Baffle #11	1,019.68	Downwards	64.39	2.2
Baffle #14	1,105.4	Upwards	64.39	2.2
Baffle #13	1,191.13	Downwards	64.39	2.2
Baffle #16	1,276.85	Upwards	64.39	2.2
Baffle #15	1,362.58	Downwards	64.39	2.2
Baffle #18	1,448.3	Upwards	64.39	2.2
Baffle #17	1,534.03	Downwards	64.39	2.2

Baffle Material:	SA-36	
Baffle Type:	Single Segmental	
Baffle Orientation:	Horizontal	
Baffle Shell Clearance:	0.8 mm	(3.2 mm TEMA (Max))
Baffle Thickness:	10 mm	(3.2 mm TEMA)
Baffle Diameter:	253.71 mm	
Baffle Count:	18	
Maximum Tubesheet to Baffle Distance:	162.43 mm	
Maximum Baffle to Baffle Distance:	171.45 mm	
Distance from Shell Side Tubesheet Face to Bend:	1,633 mm	
Baffle Group Weight:	40.3 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, 2010 Edition, A11 Addenda Metric	ASME only design (TEMA Ninth Edition (2007) minimum thickness checks active)		
Description	U-tube	Class R	One pass shell	-
Shell material: SA-106 B Smls. Pipe				Perform ASME tube design check
Tube supports\baffle plates present	Maximum tubesheet to tube support distance: 162.43 mm	Maximum tube support separation: 171.45 mm		Baffles support all tubes: No

Tube Options				
Tube material: SA-179 Smls. Tube	Tube length from outer tubesheet face to bend: L_t= 1,700 mm			
Tube dimensions, new, mm	d_o= 25.4	t_t= 2.77 (2.42 min)	Inner corrosion: 0	Outer corrosion: 0
Tube to tubesheet joint option	Tube to tubesheet joint calculations have not been performed			

Channel and Shell Options						
Shell dimensions new, mm	NPS 10 Sch 40S (Std)	D_i= 254.51	t_s= 9.27	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-106 B Smls. Pipe		D_i= 254.51	t_c= 9.27	L= 348
	Closure	SA-234 WPB		D_i= 254.51	t_{min}= 9.27	L_{SF}= 58.7

Tubesheet Options							
Tube Layout	Tube hole count: 30			Tube pitch: 31.75 mm		Pattern: 30° (triangular)	
Tubesheet dimensions, mm (front and rear)	Material: SA-266 2	T = 67	OD = 386	Shell side corrosion = 3	Tube side corrosion = 3	MDMT = -29 °C	Tubesheet pass groove depth = 5
	Impact test is not performed	Not normalized	Produced fine grain practice	PWHT not performed		Gasketed shell side	Gasketed tube side

Design Conditions Summary

Design Conditions				
Description		Design	Tube side hydrotest	Shell side hydrotest
Tube Side	Pressure (kPa)	750	2,058.08	0
	Design temperature (°C)	150	21.11	21.11
Shell Side	Pressure (kPa)	1,100	0	1,434.08
	Design temperature (°C)	65	21.11	21.11
Tubes	Design temperature (°C)	150	21.11	21.11
	E_t (MPa)	201,733.337	202,272.22	202,272.22
	S_t (MPa)	92.4	161.1	161.1
Shell	E_s (MPa)	203,609.993	202,272.22	202,272.22
	S_s (MPa)	118	216.9	216.9
Tubesheet	Design temperature (°C)	150	21.11	21.11
	S (MPa)	138	223.2	223.2

Materials and Gaskets Summary

Materials And Gaskets				
Part	**Quantity**	**Size**	**Material**	**Gasket**
Front ellipsoidal head	1	254.51 ID x 9.27 mm min thk	SA-234 WPB	-
Front channel cylinder	1	254.51 ID x 9.27 thk x 348.00 mm	SA-106 B Smls. Pipe	-
Tube Side Flange (front)	1	386.00 OD x 36 mm thk	SA-266 2	304.00 OD x 284.00 ID x 3.20 mm thk
Front tubesheet	1	386.00 OD x 67 mm thk	SA-266 2	
Shell Side Flange (front)	1	386.00 OD x 36 mm thk	SA-266 2	304.00 OD x 284.00 ID x 3.20 mm thk
Front Tubesheet flange bolts	16	0.75 in dia. stud x 202.72 mm long	SA-193 B7	-
Tubes	15	25.40 OD x 2.77 nom wall (2.42 min) mm	SA-179 Smls. Tube	-
Shell cylinder	1	NPS 10 Sch 40S (Std) x 1769.00 mm	SA-106 B Smls. Pipe	-
Rear ellipsoidal head	1	254.51 ID x 9.27 mm min thk	SA-234 WPB	-
Front pass partition	-	10 mm thk	SA-516 70	-

Nozzle Materials And Gaskets				
Part	**Quantity**	**Size**	**Material**	**Gasket**
TS Inlet (N1)	1	3 in 150# WN	A105	-
	1	NPS 3 Sch 40 (Std) DN 80	SA-106 B Smls. Pipe	
	1	88.90 ID x 50.00 wide x 9 mm thk pad	SA-516 70	
Bolts for TS Inlet (N1)	4	0.625 in dia. bolt x 76.2 mm long	SA-193 B7	
TS Outlet (N2)	1	3 in 150# WN	A105	-
	1	NPS 3 Sch 40 (Std) DN 80	SA-106 B Smls. Pipe	
	1	88.90 ID x 50.00 wide x 9 mm thk pad	SA-516 70	
Bolts for TS Outlet (N2)	4	0.625 in dia. bolt x 76.2 mm long	SA-193 B7	
SS Inlet (N3)	1	2 in 150# WN	A105	-
	1	NPS 2 Sch 80 (XS) DN 50	SA-106 B Smls. Pipe	
	1	60.33 ID x 50.00 wide x 9 mm thk pad	SA-516 70	
Bolts for SS Inlet (N3)	4	0.625 in dia. bolt x 69.85 mm long	SA-193 B7	
SS Outlet (N4)	1	2 in 150# WN	A105	-
	1	NPS 2 Sch 80 (XS) DN 50	SA-106 B Smls. Pipe	
	1	60.33 ID x 50.00 wide x 9 mm thk pad	SA-516 70	
Bolts for SS Outlet (N4)	4	0.625 in dia. bolt x 69.85 mm long	SA-193 B7	

TEMA RCB-9.132 Pass Partition Plate Calculations

Minimum Front Pass Partition Plate Thickness

Front tube side pressure drop:	q = 2	kPa
Front pass plate material:		SA-516 70 (II-D Metric p. 18, ln. 19)
Front pass plate allowable stress:	S = 138	MPa
Front pass plate dimension:	a = 253.01	mm
Front pass plate dimension:	b = 417.98	mm
Front pass plate thickness, new:	T = 10	mm
Front pass plate corrosion allowance:	C = 6	mm
Front pass plate fillet weld leg size, new	7	mm

From TABLE RCB-9.131

t = 9.5 mm

From TABLE RCB-9.132, three sides fixed, a/b = 0.6053, *B* = 0.1198

$t = b*(q*B/(1.5*S))^{1/2} + C$
$= 417.98*(0*0.1198/(1.5*138))^{1/2} + 6$
= 6.45 mm

The pass partition plate thickness of 10 mm is adequate.

Pass partition minimum weld size = 0.75*(t - C) + (C / 2) / 0.7
= 0.75*(6.45 - 6) + (6 / 2) / 0.7
= 4.62 mm

The pass partition fillet weld size of 7 mm is adequate.

Tubes

ASME Section VIII Division 1, 2010 Edition, A11 Addenda 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 = 750 kPa @ 150 °C
External design pressure: P_e = 1,100 kPa @ 150 °C

Static liquid head:

P_{th} = 3.96 kPa (SG = 1, H_s = 404.6 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 = 2.9 kg	corr = 2.9 kg
Capacity	New = 0.59 liters	corr = 0.59 liters

OD	=	25.4 mm
Length L_c	=	1,700 mm
t	=	2.77 mm

Design thickness, (at 150 °C) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 750*12.7 / (92,400*1.00 + 0.40*750) + 0
= 0.1 mm

Maximum allowable working pressure, (at 150 °C) Appendix 1-1

P = S*E*t / (R_o - 0.40*t) - P_s
= 92,400*1.00*2.42 / (12.7 - 0.40*2.42) - 0
= 19,091.64 kPa

Maximum allowable pressure, (at 21.11 °C) Appendix 1-1

P = S*E*t / (R_o - 0.40*t)
= 92,400*1.00*2.42 / (12.7 - 0.40*2.42)
= 19,091.64 kPa

External Pressure, (Corroded & at 150 °C) UG-28(c)

L / D_o	=	1,700 / 25.4	=	50.0000
D_o / t	=	25.4 / 0.49	=	51.3993
From table G:		A	=	0.000421
From table CS-1 Metric:		B	=	42.4019 MPa

P_a = $4*B / (3*(D_o / t))$
= 4*42,401.87 / (3*(25.4 / 0.49))
= 1,099.93 kPa

Design thickness for external pressure P_a = 1,099.93 kPa

t_a = t + Corrosion = 0.49 + 0 = 0.49 mm

Maximum Allowable External Pressure, (Corroded & at 150 °C) UG-28(c)

L / D_o	=	1,700 / 25.4	=	50.0000
D_o / t	=	25.4 / 2.42	=	10.4796
From table G:		A	=	0.010505
From table CS-1 Metric:		B	=	95.1 MPa

P_a = $4*B / (3*(D_o / t))$
= 4*95,100 / (3*(25.4 / 2.42))
= 12,099.66 kPa

Tubesheet -- ASME

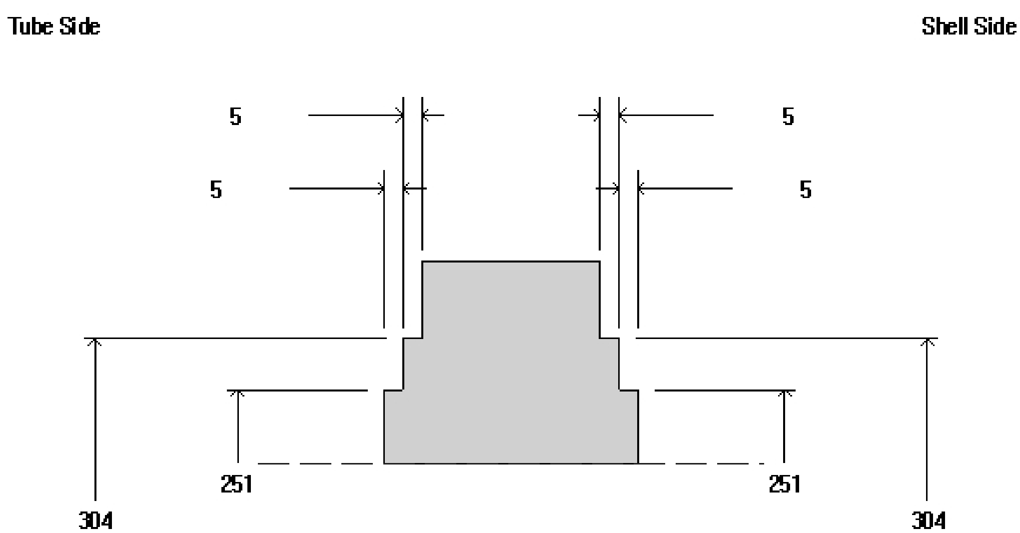
ASME Section VIII, Division 1, 2010 Edition, A11 Addenda Metric

Tubesheet

Type of heat exchanger:	U-Tube
Type of construction:	Fig. UHX-12.1 Configuration d: tubesheet gasketed with shell and channel
Simply supported:	No
Tubesheet material specification:	SA-266 2 (II-D Metric p. 18, ln. 8)
Tube layout:	Triangular
Tubesheet outer diameter, A:	386 mm
Tubesheet thickness, h:	67 mm (t_{design} = 22.46 mm)
Number of tubes, N_t:	15
Tube pitch, p:	31.75 mm
Radius to outer tube center, r_o:	102.97 mm
Total area of untubed lanes, A_L:	0.0065 m^2
Pass partition groove depth, h_g:	5 mm
Corrosion allowance shell side , c_s:	3 mm
Corrosion allowance tube side , c_t:	3 mm
Tubesheet poisson's ratio, ν:	0.3

Stepped Tubesheet

Step 1 diameter shell side	304 mm
Step 1 depth shell side	5 mm
Step 2 diameter shell side	251 mm
Step 2 depth shell side	5 mm
Step 1 diameter tube side	304 mm
Step 1 depth tube side	5 mm
Step 2 diameter tube side	251 mm
Step 2 depth tube side	5 mm



Shell

Shell material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Shell inner diameter, D_s:	254.51 mm
Shell thickness, t_s:	9.27 mm
Shell inner corrosion allowance:	3 mm
Shell outer corrosion allowance:	0 mm
Shell poisson's ratio, ν_s:	0.31

Channel

Channel material specification: SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Channel inner diameter, D_c: 254.51 mm
Channel thickness, t_c: 9.27 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: 25.4 mm
Tube nominal thickness, t_t: 2.77 mm
Tube minimum thickness, $t_{t,min}$: 2.42 mm
Tube tolerance: 12.5%
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: 344 mm
Shell side gasket load reaction diameter, G_s: 294 mm
Channel side gasket load reaction diameter, G_c: 294 mm

Tube Supports

Tube supports present: Yes
Support all tubes: No
Maximum distance from tubesheet to first support: 162.43 mm
Maximum distance between tube supports: 171.45 mm

Summary Tables

Tubesheet Design Thickness Summary

Condition	t_{design} (mm)
Design	22.4579618
Tube side hydrotest	39.3115698
Shell side hydrotest	37.5888626

Tubesheet Effective Bolt Load

Condition	Load Case	W^* (N)
Design	Load case 1	93,854.61
	Load case 2	115,256.54
	Load case 3	115,256.54
Tube side hydrotest	Load case 1	257,547.05
Shell side hydrotest	Load case 2	150,260.78

Pressures and Temperatures						
Condition	Shell side design pressure P_s (kPa)	Tube side design pressure P_t (kPa)	Tubesheet design temp T (°C)	Shell design temp T_s (°C)	Channel design temp T_c (°C)	Tube design temp T_t (°C)
Design	1,100	750	150	65	150	150
Tube side hydrotest	0	2,058.08	21.11	21.11	21.11	21.11
Shell side hydrotest	1,434.08	0	21.11	21.11	21.11	21.11

Material Properties					
Condition	Component	Material	Modulus of Elasticity (MPa)	Allowable Stress (MPa)	Yield Stress (MPa)
Design	Shell	SA-106 B Smls. Pipe	E_s = 199,867	S_s = 118	$S_{y,s}$ =227
	Channel	SA-106 B Smls. Pipe	E_c =195,000	S_c =118	$S_{y,c}$ =214
	Tubesheet	SA-266 2	E =195,000	S =138	S =219
	Tubes	SA-179 Smls. Tube	E_t =195,000	S_t =92.4	$S_{y,t}$ =158
			E_{tT} =195,000	S_{tT} =92.4	N/A
Tube side hydrotest	Shell	SA-106 B Smls. Pipe	E_s = 202,272	S_s = 216.9	$S_{y,s}$ =241
	Channel	SA-106 B Smls. Pipe	E_c =202,272	S_c =216.9	$S_{y,c}$ =241
	Tubesheet	SA-266 2	E =202,272	S =223.2	S =248
	Tubes	SA-179 Smls. Tube	E_t =202,272	S_t =161.1	$S_{y,t}$ =179
			E_{tT} =202,272	S_{tT} =161.1	N/A
Shell side hydrotest	Shell	SA-106 B Smls. Pipe	E_s = 202,272	S_s = 216.9	$S_{y,s}$ =241
	Channel	SA-106 B Smls. Pipe	E_c =202,272	S_c =216.9	$S_{y,c}$ =241
	Tubesheet	SA-266 2	E =202,272	S =223.2	S =248
	Tubes	SA-179 Smls. Tube	E_t =202,272	S_t =161.1	$S_{y,t}$ =179
			E_{tT} =202,272	S_{tT} =161.1	N/A

Calculations for Design Condition

UHX-12.5.1 Step 1		
$D_o = 2*r_o + d_t$		
$\mu = (p - d_t) / p$		
$d^* = MAX\{[d_t - 2*t_t*(E_{tT} / E)*(S_{tT} / S)*\rho], [d_t - 2*t_t]\}$		
$p^* = p / (1 - 4*MIN(A_L, 4*D_o*p) / (\pi*D_o^2))^{0.5}$		
$\mu^* = (p^* - d^*) / p^*$		
$h_g' = MAX[(h_g - c_t), 0]$		
Condition Design		
New or corroded	$D_o = 2*102.97 + 25.4 =$	231.34
New or corroded	$\mu = (31.75 - 25.4) / 31.75 =$	0.2
New	$d^* = MAX\{[25.4 - 2*2.77*(195,000 / 195,000)*(92.4 / 138)*0.85], [25.4 - 2*2.77]\} =$	22.2470175
Corroded	$d^* = MAX\{[25.4 - 2*2.77*(195,000 / 195,000)*(92.4 / 138)*0.8844], [25.4 - 2*2.77]\} =$	22.1193171
New or corroded	$p^* = 31.75 / (1 - 4*MIN(0.0065, 4*231.34*31.75) / (\pi*231.34^2))^{0.5} =$	34.51
New	$\mu^* = (34.5085984 - 22.2470175) / 34.5085984 =$	0.35532
Corroded	$\mu^* = (34.5085984 - 22.1193171) / 34.5085984 =$	0.35902
	$h_g' =$	2

UHX-12.5.2 Step 2			
$\rho_s = G_s / D_o$			
$\rho_c = G_c / D_o$			
$M_{TS} = D_o^2 / 16 *[(\rho_s -1)*(\rho_s^2 + 1)*P_s - (\rho_c - 1)*(\rho_c^2 + 1)*P_t]$			
Condition Design			
New or corroded	All load cases	$\rho_s = 294 / 231.34 =$	1.2709
New or corroded	All load cases	$\rho_c = 294 / 231.34 =$	1.2709
New or corroded	Load case 1	$M_{TS} = 231.34^2 / 16 *[(1.2708567 -1)*(1.2708567^2 + 1)*0 - (1.2708567 - 1)*(1.2708567^2 + 1)*750] / 1000 =$	-1,776.92
	Load case 2	$M_{TS} = 231.34^2 / 16 *[(1.2708567 -1)*(1.2708567^2 + 1)*1,100 - (1.2708567 - 1)*(1.2708567^2 + 1)*0] / 1000 =$	2,606.14
	Load case 3	$M_{TS} = 231.34^2 / 16 *[(1.2708567 -1)*(1.2708567^2 + 1)*1,100 - (1.2708567 - 1)*(1.2708567^2 + 1)*750] / 1000 =$	829.23

UHX-12.5.3 Step 3		
$E^* / E = \alpha_0 + \alpha_1 * \mu^* + \alpha_2 * \mu^{*2} + \alpha_3 * \mu^{*3} + \alpha_4 * \mu^{*4}$		
$\nu^* = \beta_0 + \beta_1 * \mu^* + \beta_2 * \mu^{*2} + \beta_3 * \mu^{*3} + \beta_4 * \mu^{*4}$		
Condition Design		
New	h / p = 67 / 31.75 =	2.1102
Corroded	h / p = 61 / 31.75 =	1.9213
New	- from Fig. UHX-11.3(a) E^* / E =	0.3542
Corroded	- from Fig. UHX-11.3(a) E^* / E =	0.3622
New	E^* = 0.3542265*195,000 =	69,074.163
Corroded	E^* = 0.362214*195,000 =	70,631.734
New	- from Fig. UHX-11.3(b) ν^* =	0.3244
Corroded	- from Fig. UHX-11.3(b) ν^* =	0.3208

UHX-12.5.5 Step 5			
$K = A / D_o$			
$F = ((1 - \nu^*) / E^*)*(E*\ln(K))$			
Condition Design			
New or corroded	All load cases	K = 386 / 231.34 =	1.6685
New	All load cases	F = ((1 - 0.3243672) / 69,074.163)*(195,000*ln(1.6685)) =	0.9765
Corroded	All load cases	F = ((1 - 0.3207623) / 70,631.734)*(195,000*ln(1.6685)) =	0.96

UHX-12.5.6 Step 6			
$M^* = M_{TS} + W^{*}*(G_c - G_s) / (2*\pi*D_o)$			
Condition Design			
New or corroded	Load case 1	M^* = -1,776.92 + 93,854.61*(294 - 294) / (2*π*231.34) =	-1,776.92
	Load case 2	M^* = 2,606.14 + 115,256.54*(294 - 294) / (2*π*231.34) =	2,606.14
	Load case 3	M^* = 829.23 + 115,256.54*(294 - 294) / (2*π*231.34) =	829.23

UHX-12.5.7 Step 7			
$M_p = (M^* - (D_o^2 / 32)*F*(P_s - P_t)) / (1 + F)$			
$M_o = M_p + (D_o^2 / 64)*(3 + \nu^*)*(P_s - P_t)$			
$M = Max[Abs(M_p),Abs(M_o)]$			
Condition Design			
New	Load case 1	$M_p = (-1,776.92 - (231.34^2 / 32)*0.9765*(0 - 750) / 1000) / (1 + 0.9765) =$	-279.34
	Load case 2	$M_p = (2,606.14 - (231.34^2 / 32)*0.9765*(1,100 - 0) / 1000) / (1 + 0.9765) =$	409.7
	Load case 3	$M_p = (829.23 - (231.34^2 / 32)*0.9765*(1,100 - 750) / 1000) / (1 + 0.9765) =$	130.36
Corroded	Load case 1	$M_p = (-1,776.92 - (231.34^2 / 32)*0.96*(0 - 750) / 1000) / (1 + 0.96) =$	-292.2
	Load case 2	$M_p = (2,606.14 - (231.34^2 / 32)*0.96*(1,100 - 0) / 1000) / (1 + 0.96) =$	428.56
	Load case 3	$M_p = (829.23 - (231.34^2 / 32)*0.96*(1,100 - 750) / 1000) / (1 + 0.96) =$	136.36
New	Load case 1	$M_o = -279.3397 + (231.34^2 / 64)*(3 + 0.3243672)*(0 - 750) / 1000 =$	-2,364.27
	Load case 2	$M_o = 409.6983 + (231.34^2 / 64)*(3 + 0.3243672)*(1,100 - 0) / 1000 =$	3,467.6
	Load case 3	$M_o = 130.3585 + (231.34^2 / 64)*(3 + 0.3243672)*(1,100 - 750) / 1000 =$	1,103.33
Corroded	Load case 1	$M_o = -292.202 + (231.34^2 / 64)*(3 + 0.3207623)*(0 - 750) / 1000 =$	-2,374.87
	Load case 2	$M_o = 428.5629 + (231.34^2 / 64)*(3 + 0.3207623)*(1,100 - 0) / 1000 =$	3,483.15
	Load case 3	$M_o = 136.3609 + (231.34^2 / 64)*(3 + 0.3207623)*(1,100 - 750) / 1000 =$	1,108.27
New	Load case 1	M = Max[Abs(-279.3397),Abs(-2,364.27)] =	2,364.27
	Load case 2	M = Max[Abs(409.6983),Abs(3,467.6)] =	3,467.6
	Load case 3	M = Max[Abs(130.3585),Abs(1,103.33)] =	1,103.33
Corroded	Load case 1	M = Max[Abs(-292.202),Abs(-2,374.87)] =	2,374.87
	Load case 2	M = Max[Abs(428.5629),Abs(3,483.15)] =	3,483.15
	Load case 3	M = Max[Abs(136.3609),Abs(1,108.27)] =	1,108.27

UHX-12.5.8 Step 8					
$\sigma = 6*M / (\mu^* *(h - h_g')^2)$					
Condition Design			Stress (MPa)	Allowable 2*S (MPa)	Over-stressed?
New	Load case 1	$\sigma = 6*2,364.2713 / (0.3553196*(67 - 5)^2) =$	10.386	276	No
	Load case 2	$\sigma = 6*3,467.5978 / (0.3553196*(67 - 5)^2) =$	15.233	276	No
	Load case 3	$\sigma = 6*1,103.3266 / (0.3553196*(67 - 5)^2) =$	4.847	276	No
Corroded	Load case 1	$\sigma = 6*2,374.8727 / (0.3590201*(61 - 2)^2) =$	11.402	276	No
	Load case 2	$\sigma = 6*3,483.1466 / (0.3590201*(61 - 2)^2) =$	16.722	276	No
	Load case 3	$\sigma = 6*1,108.2739 / (0.3590201*(61 - 2)^2) =$	5.321	276	No

UHX-12.5.9 Step 9					
$\tau = (1 / (4*\mu))*(D_o / h)*ABS(P_s - P_t)$					
Condition Design					
Tubesheet Shear Stress			Stress (MPa)	Allowable (MPa)	Over-stressed?
New	Load case 1	$\tau = (1 / (4*0.2))*(231.34 / 67)*ABS(0 - 750) / 1000 =$	3.237	110.4	No
	Load case 2	$\tau = (1 / (4*0.2))*(231.34 / 67)*ABS(1,100 - 0) / 1000 =$	4.748	110.4	No
	Load case 3	$\tau = (1 / (4*0.2))*(231.34 / 67)*ABS(1,100 - 750) / 1000 =$	1.511	110.4	No
Corroded	Load case 1	$\tau = (1 / (4*0.2))*(231.34 / 61)*ABS(0 - 750) / 1000 =$	3.555	110.4	No
	Load case 2	$\tau = (1 / (4*0.2))*(231.34 / 61)*ABS(1,100 - 0) / 1000 =$	5.215	110.4	No
	Load case 3	$\tau = (1 / (4*0.2))*(231.34 / 61)*ABS(1,100 - 750) / 1000 =$	1.659	110.4	No

Calculations for Tube side hydrotest Condition

UHX-9.5			
$h_r = (1.9*W*h_g / (S*G))^{0.5}$			
Condition Tube side hydrotest			
Operating			
New	Load case 1	$h_r = (1.9*257,547.05*25 / (223.2*294))^{0.5} =$	13.65
Gasket Seating			
New	Load case 1	$h_r = (1.9*515,148.64*25 / (223.2*294))^{0.5} =$	19.31
Tubesheet Design Thickness to Maintain h_r = 19.31 + 10 + 10 = 39.31 mm			

UHX-12.5.1 Step 1		
$D_o = 2*r_o + d_t$		
$\mu = (p - d_t) / p$		
$d^* = MAX\{[d_t - 2*t_t*(E_{tT} / E)*(S_{tT} / S)*\rho], [d_t - 2*t_t]\}$		
$p^* = p / (1 - 4*MIN(A_L, 4*D_o*p) / (\pi*D_o^2))^{0.5}$		
$\mu^* = (p^* - d^*) / p^*$		
$h_g' = MAX[(h_g - c_t), 0]$		
Condition Tube side hydrotest		
New	D_o = 2*102.97 + 25.4 =	231.34
New	μ = (31.75 - 25.4) / 31.75 =	0.2
New	d^* = MAX{[25.4 - 2*2.77*(202,272.22 / 202,272.22)*(161.1 / 223.2)*0.85], [25.4 - 2*2.77]} =	22.0011653
New	p^* = 31.75 / (1 - 4*MIN(0.0065, 4*231.34*31.75) / (π*231.34^2))$^{0.5}$ =	34.51
New	μ^* = (34.5085984 - 22.0011653) / 34.5085984 =	0.362444
	h_g' =	5

UHX-12.5.2 Step 2			
$\rho_s = G_s / D_o$			
$\rho_c = G_c / D_o$			
$M_{TS} = D_o^2 / 16 *[(\rho_s -1)*(\rho_s^2 + 1)*P_s - (\rho_c - 1)*(\rho_c^2 + 1)*P_t]$			
Condition Tube side hydrotest			
New	All load cases	ρ_s = 294 / 231.34 =	1.2709
New	All load cases	ρ_c = 294 / 231.34 =	1.2709
New	Load case 1	M_{TS} = 231.34^2 / 16 *[(1.2708567 -1)*(1.2708567^2 + 1)*0 - (1.2708567 - 1)*(1.2708567^2 + 1)*2,058.08] / 1000 =	-4,876.05

UHX-12.5.3 Step 3		
$E^* / E = \alpha_0 + \alpha_1*\mu^* + \alpha_2*\mu^{*2} + \alpha_3*\mu^{*3} + \alpha_4*\mu^{*4}$		
$\nu^* = \beta_0 + \beta_1*\mu^* + \beta_2*\mu^{*2} + \beta_3*\mu^{*3} + \beta_4*\mu^{*4}$		
Condition Tube side hydrotest		
New	h / p = 67 / 31.75 =	2.1102
New	- from Fig. UHX-11.3(a) E^* / E =	0.3637
New	E^* = 0.3636735*202,272.22 =	73,561.053
New	- from Fig. UHX-11.3(b) ν^* =	0.3217

UHX-12.5.5 Step 5			
$K = A / D_o$			
$F = ((1 - \nu^*) / E^*)*(E*\ln(K))$			
Condition Tube side hydrotest			
New	All load cases	K = 386 / 231.34 =	1.6685
New	All load cases	F = ((1 - 0.3216675) / 73,561.053)*(202,272.22*ln(1.6685)) =	0.9549

UHX-12.5.6 Step 6			
$M^* = M_{TS} + W^**(G_c - G_s) / (2*\pi*D_o)$			
Condition Tube side hydrotest			
New	Load case 1	M^* = -4,876.05 + 257,547.05*(294 - 294) / (2*π*231.34) =	-4,876.05

UHX-12.5.7 Step 7			
$M_p = (M^* - (D_o^2 / 32)*F*(P_s - P_t)) / (1 + F)$			
$M_o = M_p + (D_o^2 / 64)*(3 + \nu^*)*(P_s - P_t)$			
$M = Max[Abs(M_p),Abs(M_o)]$			
Condition Tube side hydrotest			
New	Load case 1	M_p = (-4,876.05 - (231.34^2 / 32)*0.9549*(0 - 2,058.08) / 1000) / (1 + 0.9549) =	-812.96
New	Load case 1	M_o = -812.9639 + (231.34^2 / 64)*(3 + 0.3216675)*(0 - 2,058.08) / 1000 =	-6,529.59
New	Load case 1	M = Max[Abs(-812.9639),Abs(-6,529.59)] =	6,529.59

UHX-12.5.8 Step 8					
$\sigma = 6*M / (\mu^{**}*(h - h_g')^2)$					
Condition Tube side hydrotest			**Stress (MPa)**	**Allowable (MPa)**	**Over-stressed?**
New	Load case 1	$\sigma = 6*6{,}529.5922 / (0.362444*(67 - 5)^2) =$	28.12	446.4	No

UHX-12.5.9 Step 9					
$\tau = (1 / (4*\mu))*(D_o / h)*ABS(P_s - P_t)$					
Condition Tube side hydrotest					
Tubesheet Shear Stress			**Stress (MPa)**	**Allowable (MPa)**	**Over-stressed?**
New	Load case 1	$\tau = (1 / (4*0.2))*(231.34 / 67)*ABS(0 - 2{,}058.08) / 1000 =$	8.883	178.56	No

Calculations for Shell side hydrotest Condition

UHX-9.5			
Condition Shell side hydrotest			
Operating			
New	Load case 2	$h_r = (1.9*150{,}260.78*25 / (223.2*294))^{0.5} =$	10.43
Gasket Seating			
New	Load case 2	$h_r = (1.9*427{,}342.67*25 / (223.2*294))^{0.5} =$	17.59
Tubesheet Design Thickness to Maintain h_r = 17.59 + 10 + 10 = 37.59 mm			

UHX-12.5.1 Step 1		
$D_o = 2*r_o + d_t$		
$\mu = (p - d_t) / p$		
$d^* = MAX\{[d_t - 2*t_t*(E_{tT} / E)*(S_{tT} / S)*\rho], [d_t - 2*t_t]\}$		
$p^* = p / (1 - 4*MIN(A_L, 4*D_o*p) / (\pi*D_o^2))^{0.5}$		
$\mu^* = (p^* - d^*) / p^*$		
$h_g' = MAX[(h_g - c_t), 0]$		
Condition Shell side hydrotest		
New	D_o = 2*102.97 + 25.4 =	231.34
New	μ = (31.75 - 25.4) / 31.75 =	0.2
New	d^* = MAX{[25.4 - 2*2.77*(202,272.22 / 202,272.22)*(161.1 / 223.2)*0.85], [25.4 - 2*2.77]} =	22.0011653
New	p^* = 31.75 / (1 - 4*MIN(0.0065, 4*231.34*31.75) / (π*231.34^2))$^{0.5}$ =	34.51
New	μ^* = (34.5085984 - 22.0011653) / 34.5085984 =	0.362444
	h_g' =	5

UHX-12.5.2 Step 2			
$\rho_s = G_s / D_o$			
$\rho_c = G_c / D_o$			
$M_{TS} = D_o^2 / 16 *[(\rho_s -1)*(\rho_s^2 + 1)*P_s - (\rho_c - 1)*(\rho_c^2 + 1)*P_t]$			
Condition Shell side hydrotest			
New	All load cases	ρ_s = 294 / 231.34 =	1.2709
New	All load cases	ρ_c = 294 / 231.34 =	1.2709
New	Load case 2	M_{TS} = 231.34^2 / 16 *[(1.2708567 -1)*(1.2708567^2 + 1)*1,434.08 - (1.2708567 - 1)*(1.2708567^2 + 1)*0] / 1000 =	3,397.65

UHX-12.5.3 Step 3		
$E^* / E = \alpha_0 + \alpha_1*\mu^* + \alpha_2*\mu^{*2} + \alpha_3*\mu^{*3} + \alpha_4*\mu^{*4}$		
$\nu^* = \beta_0 + \beta_1*\mu^* + \beta_2*\mu^{*2} + \beta_3*\mu^{*3} + \beta_4*\mu^{*4}$		
Condition Shell side hydrotest		
New	h / p = 67 / 31.75 =	2.1102
New	- from Fig. UHX-11.3(a) E^* / E =	0.3637
New	E^* = 0.3636735*202,272.22 =	73,561.053
New	- from Fig. UHX-11.3(b) ν^* =	0.3217

UHX-12.5.5 Step 5			
$K = A / D_o$			
$F = ((1 - \nu^*) / E^*)*(E*\ln(K))$			
Condition Shell side hydrotest			
New	All load cases	K = 386 / 231.34 =	1.6685
New	All load cases	F = ((1 - 0.3216675) / 73,561.053)*(202,272.22*ln(1.6685)) =	0.9549

UHX-12.5.6 Step 6			
$M^* = M_{TS} + W^**(G_c - G_s) / (2*\pi*D_o)$			
Condition Shell side hydrotest			
New	Load case 2	M^* = 3,397.65 + 150,260.78*(294 - 294) / (2*π*231.34) =	3,397.65

UHX-12.5.7 Step 7			
$M_p = (M^* - (D_o^2 / 32)*F*(P_s - P_t)) / (1 + F)$			
$M_o = M_p + (D_o^2 / 64)*(3 + \nu^*)*(P_s - P_t)$			
$M = Max[Abs(M_p),Abs(M_o)]$			
Condition Shell side hydrotest			
New	Load case 2	M_p = (3,397.65 - (231.34^2 / 32)*0.9549*(1,434.0779 - 0) / 1000) / (1 + 0.9549) =	566.48
New	Load case 2	M_o = 566.4763 + (231.34^2 / 64)*(3 + 0.3216675)*(1,434.0779 - 0) / 1000 =	4,549.84
New	Load case 2	M = Max[Abs(566.4763),Abs(4,549.84)] =	4,549.84

UHX-12.5.8 Step 8					
$\sigma = 6*M / (\mu^{*}*(h - h_g')^2)$					
Condition Shell side hydrotest			Stress (MPa)	Allowable (MPa)	Over-stressed?
New	Load case 2	$\sigma = 6*4,549.8445 / (0.362444*(67 - 5)^2) =$	19.594	446.4	No

UHX-12.5.9 Step 9					
$\tau = (1 / (4*\mu))*(D_o / h)*ABS(P_s - P_t)$					
Condition Shell side hydrotest					
Tubesheet Shear Stress			Stress (MPa)	Allowable (MPa)	Over-stressed?
New	Load case 2	$\tau = (1 / (4*0.2))*(231.34 / 67)*ABS(1,434.08 - 0) / 1000 =$	6.19	178.56	No

Tubesheet Maximum Pressure Report

ASME Tubesheet Maximum Pressure Ratings				
Description		Design	Tube side hydrotest	Shell side hydrotest
Tube Side	Pressure (kPa)	18,155.21	24,386.47	0
	Design temperature (°C)	150	21.11	21.11
Shell Side	Pressure (kPa)	18,155.21	0	29,125.26
	Design temperature (°C)	65	21.11	21.11
Tubes	Design temperature (°C)	150	21.11	21.11
Tubesheet	Design temperature (°C)	150	21.11	21.11