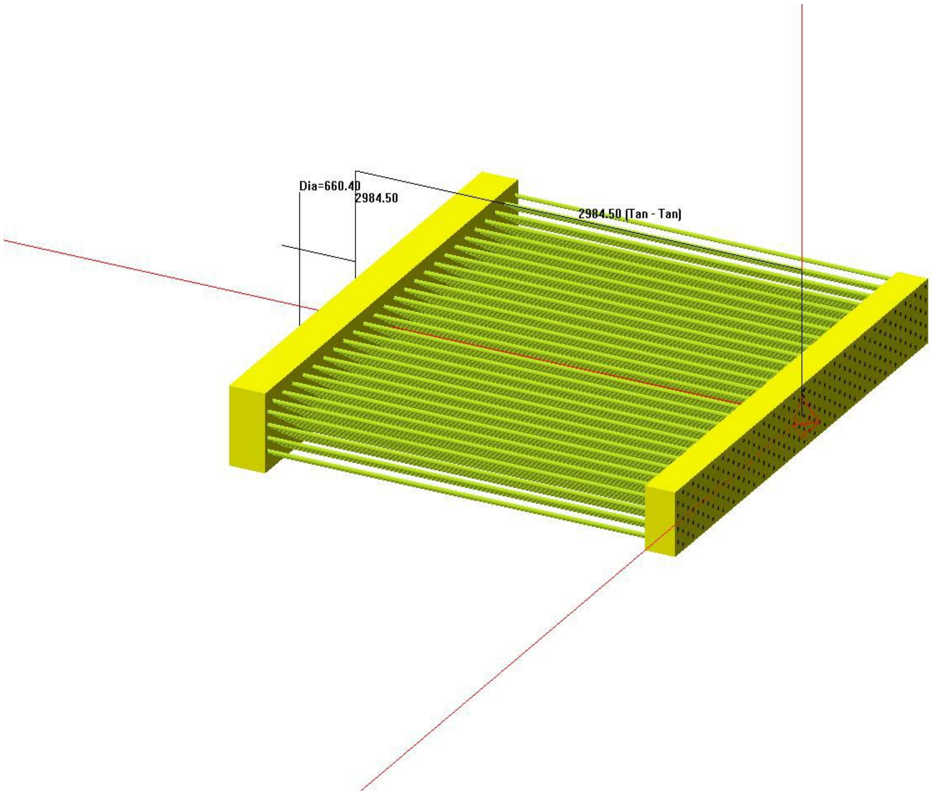
Your Company Name

Your Company Address



Item:

Vessel No:

Customer:

Contract:

Designer:

Date: Tuesday, May 30, 2023

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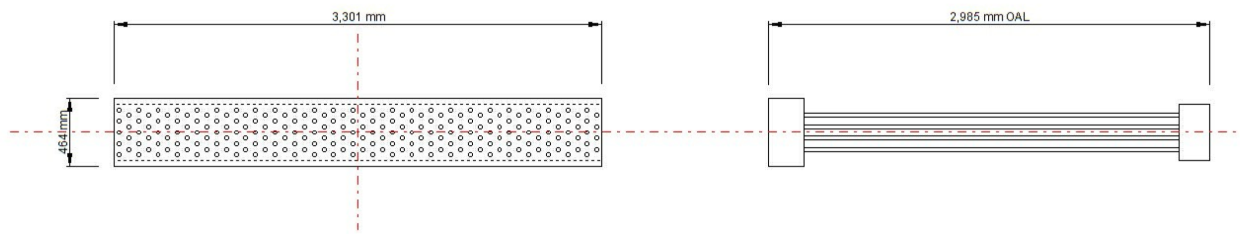

DESIGN DATA

Design Pressure	6.89 bar
Vacuum Pressure	1.03 bar
Test Pressure (Shop)	30.17 bar
Design Temperature	343.33 °C
MDMT	-28.89 °C
Corrosion Allowance	0 mm
PWHT	HT

Estimated Weights

Dry:	2,525 kg	Wet:	2,525 kg

Materials

Tube/Plug plate:	SA-516 70
Top/Bottom plate:	SA-516 70
End plate:	SA-516 70
Tubes:	SA-179 Smls Tube
Stays:	SA-516 70

NOZZLE SCHEDULE

MARK	NOZZLE	SIZE & SCH	FLANGE	MARK	NOZZLE	SIZE & SCH	FLANGE

REVISIONS

REV	DATE	DESCRIPTION
0	02/17/2022	FOR APPROVAL

Codeware, Inc.
2600 Washington Blvd.
Dallas, TX, 75204

DWN BY:
CHK BY:
145685-1

General Arrangement

DWG NO. DATE: Rev 0

Comp2

Deficiencies Summary

No deficiencies found.

Pressure Summary

Component Summary										
Identifier		P Design (bar)	T Design (°C)	MAWP (bar)	MAP (bar)	MAEP (bar)	T_e external (°C)	MDMT (°C)	MDMT Exemption	Impact Tested
Inlet/Outlet Header	Tubesheet	6.89	343.33	34.26	36.65	N/A	343.33	-48	Note 1	No
	Plugsheet	6.89	343.33	33.82	36.18	N/A	343.33	-48	Note 2	No
	Top / Bottom Plate	6.89	343.33	24.38	26.08	N/A	343.33	-40.25	Note 3	No
	End Plates	6.89	343.33	22.26	23.81	22.26	343.33	-44.01	Note 4	No
	Stay Plates	6.89	343.33	74.19	79.37	N/A	343.33	-105	Note 5	No
Tubes		6.89	343.33	212.4	221.51	114.25	343.33	-105	Note 6	No
Return Header	Tubesheet	6.89	343.33	50.33	53.84	N/A	343.33	-48	Note 7	No
	Plugsheet	6.89	343.33	49.68	53.15	N/A	343.33	-48	Note 8	No
	Top / Bottom Plate	6.89	343.33	37.18	39.77	N/A	343.33	-48	Note 9	No
	End Plates	6.89	343.33	33.76	36.11	33.76	343.33	-48	Note 10	No
	Stay Plates	6.89	343.33	90.8	97.13	N/A	343.33	-105	Note 11	No

Chamber Summary	
Design MDMT	-28.89 °C
Rated MDMT	-28.89 °C @ 22.26 bar
MAWP hot & corroded	22.26 bar @ 343.33 °C
MAP cold & new	23.81 bar @ 21.11 °C
MAEP	22.26 bar @ 343.33 °C
(1) The rated MDMT is limited to the design MDMT based on the setting in the Calculations tab of the Set Mode dialog.	

Notes for MDMT Rating		
Note #	**Exemption**	**Details**
1.	impact test exemption temperature from Fig UCS-66M Curve B = -15.05°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 22°C, (coincident ratio = 0.6072) Rated MDMT of -54.05°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 15.88 mm
2.	impact test exemption temperature from Fig UCS-66M Curve B = -15.05°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 21.6°C, (coincident ratio = 0.6151) Rated MDMT of -53.65°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 15.88 mm
3.	impact test exemption temperature from Fig UCS-66M Curve B = -15.05°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 8.2°C, (coincident ratio = 0.8534)	UCS-66 governing thickness = 15.88 mm
4.	impact test exemption temperature from Fig UCS-66M Curve B = -23.31°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 3.7°C, (coincident ratio = 0.9348)	UCS-66 governing thickness = 12 mm
5.	is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.2804)	
6.	Material is impact test exempt per UCS-66(d) (NPS 4 or smaller pipe)	
7.	impact test exemption temperature from Fig UCS-66M Curve B = -15.05°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 47.4°C, (coincident ratio = 0.4134) Rated MDMT of -79.45°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 15.88 mm
8.	impact test exemption temperature from Fig UCS-66M Curve B = -15.05°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 45.9°C, (coincident ratio = 0.4187) Rated MDMT of -77.95°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 15.88 mm
9.	impact test exemption temperature from Fig UCS-66M Curve B = -15.05°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 26.2°C, (coincident ratio = 0.5596) Rated MDMT of -58.25°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 15.88 mm
10.	impact test exemption temperature from Fig UCS-66M Curve B = -23.31°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 21.5°C, (coincident ratio = 0.6163) Rated MDMT of -61.81°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 12 mm
11.	is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.2291)	

Settings Summary

COMPRESS 2023 Build 8310	
ASME Section VIII Division 1, 2021 Edition Metric	
Units	MKS
Datum Line Location	0.00 mm from right seam
Vessel Design Mode	Design Mode
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 only
Corrosion weight loss	100% of theoretical loss
UG-23 Stress Increase	1.20
Skirt/legs stress increase	1.0
Minimum nozzle projection	0.03 mm
Juncture calculations for α > 30 only	Yes
Preheat P-No 1 Materials > 1.25" and <= 1.50" thick	No
UG-37(a) shell tr calculation considers longitudinal stress	No
Cylindrical shells made from pipe are entered as minimum thickness	No
Nozzles made from pipe are entered as minimum thickness	No
ASME B16.9 fittings are entered as minimum thickness	No
Butt welds	Tapered per Figure UCS-66.3(a)
Disallow Appendix 1-5, 1-8 calculations under 15 psi	No
Hydro/Pneumatic Test	
Shop Hydrotest Pressure	1.3 times vessel MAWP [UG-99(b)]
Test liquid specific gravity	1.00
Maximum stress during test	90% of yield
Required Marking - UG-116	
UG-116(f) Postweld heat treatment	HT
Code Cases\Interpretations	
Use Appendix 46	No
Use UG-44(b)	No
Use Code Case 3035	No
Apply interpretation VIII-1-83-66	Yes
Apply interpretation VIII-1-86-175	Yes
Apply interpretation VIII-1-01-37	Yes
Apply interpretation VIII-1-01-150	Yes
Apply interpretation VIII-1-07-50	Yes
Apply interpretation VIII-1-16-85	Yes
No UCS-66.1 MDMT reduction	No
No UCS-68(c) MDMT reduction	No
Disallow UG-20(f) exemptions	No
Appendix 13	
Apply API 661 Requirements	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	No
UG-22(c) Superimposed static reactions from weight of attached equipment (external loads)	No
UG-22(d)(2) Vessel supports such as lugs, rings, skirts, saddles and legs	No
UG-22(f) Wind reactions	No
UG-22(f) Seismic reactions	No

UG-22(j) Test pressure and coincident static head acting during the test:	Yes
Note: UG-22(b),(c) and (f) loads only considered when supports are present.	
Note 2: UG-22(d)(1),(e),(f)-snow,(g),(h),(i) are not considered. If these loads are present, additional calculations must be performed.	

License Information	
Company Name	Codeware, Inc.
License	Commercial
License Key ID	81004
Support Expires	June 03, 2023

Thickness Summary

Header Data									
Component Identifier	**Plate**	**Material**	**Length (mm)**	**Width (mm)**	**Nominal t (mm)**	**Design t (mm)**	**Total Corrosion (mm)**	**Mid-Joint E**	**Corner-Joint E**
Inlet/Outlet Header	Top / Bottom Plate	SA-516 70	190.5	3,300.6	15.88	8.23	0	1	1
	Tubesheet	SA-516 70	463.55	3,300.6	25.4	10.91	0	1	1
	Plugsheet	SA-516 70	463.55	3,300.6	25.4	10.98	0	1	1
	End Plates	SA-516 70	190.5	431.8	12	6.68	0	1	
	Stay Plates	SA-516 70	3,276.6	190.5	12	1.12	0	1	
Return Header	Top / Bottom Plate	SA-516 70	152.4	3,300.6	15.88	6.58	0	1	1
	Tubesheet	SA-516 70	374.65	3,300.6	25.4	8.84	0	1	1
	Plugsheet	SA-516 70	374.65	3,300.6	25.4	8.9	0	1	1
	End Plates	SA-516 70	152.4	342.9	12	5.42	0	1	
	Stay Plates	SA-516 70	3,276.6	152.4	12	0.91	0	1	

Component Data								
Component Identifier	**Material**	**Diameter (mm)**	**Length (mm)**	**Nominal t (mm)**	**Design t (mm)**	**Total Corrosion (mm)**	**Joint E**	**Load**
Tubes	SA-179 Smls Tube	25.4 OD	2,590.8	3.18	0.22	0	1.00	External

Definitions	
Nominal t	Vessel wall nominal thickness
Design t	Required vessel thickness due to governing loading + corrosion
Joint E	Longitudinal seam joint efficiency
Load	
Internal	Circumferential stress due to internal pressure governs
External	External pressure governs
Wind	Combined longitudinal stress of pressure + weight + wind governs
Seismic	Combined longitudinal stress of pressure + weight + seismic governs

Weight Summary

Weight (kg) Contributed by Vessel Elements										
Component	Metal New*	Metal Corroded	Insulation	Insulation Supports	Lining	Piping + Liquid	Operating Liquid		Test Liquid	
							New	Corroded	New	Corroded
Inlet/Outlet Header	839.3	839.3	0	0	0	0	0	0	261.8	261.8
Tubes	1,012.2	1,012.2	0	0	0	0	0	0	166	166
Return Header	673.9	673.9	0	0	0	0	0	0	165.1	165.1
TOTAL:	**2,525.5**	**2,525.5**	**0**	**0**	**0**	**0**	**0**	**0**	**426.9**	**426.9**

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

Weight (kg) Contributed by Attachments									
Component	Body Flanges		Nozzles & Flanges		Packed Beds	Trays	Tray Supports	Rings & Clips	Vertical Loads
	New	Corroded	New	Corroded					
Inlet/Outlet Header	0	0	0	0	0	0	0	0	0
Return Header	0	0	0	0	0	0	0	0	0
TOTAL:	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Vessel Totals		
	New	Corroded
Operating Weight (kg)	2,525	2,525
Empty Weight (kg)	2,525	2,525
Test Weight (kg)	2,952	2,952
Capacity** (liters)	427	427

**The vessel capacity does not include volume of nozzle, piping or other attachments.

Hydrostatic Test

Horizontal shop hydrostatic test based on MAWP per UG-99(b)

Gauge pressure at 21.11°C $= 1.3 \cdot MAWP \cdot LSR$

$= 1.3 \cdot 22.26 \cdot 1.0429$

$= 30.17 \text{ bar}$

Horizontal shop hydrostatic test							
Identifier	Local test pressure (bar)	Test liquid static head (bar)	UG-99(b) stress ratio	UG-99(b) pressure factor	Stress during test (kg_f/cm^2)	Allowable test stress (kg_f/cm^2)	Stress excessive?
Tubes (1)	30.17	0	1.0429	1.30	120.219	1,651.94	No
End Plates	30.17	0	1.0698	1.30	1,783.426	3,606.736	No
End Plates	30.17	0	1.0698	1.30	1,175.749	3,606.736	No

(1) Tubes limits the UG-99(b) stress ratio.
(2) 1.5*0.9*S_y used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.
(3) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.
(4) UG-99(l): Custom flange assemblies shall be tested with gaskets having identical geometries and gasket factors, and bolting having identical allowable stress at room temperature as used in the design calculations.

The test temperature of 21.11 °C is warmer than the minimum recommended temperature of -27.01 °C so the brittle fracture provision of UG-99(h) has been met.

Bill of Materials

Appendix 13 Headers							
Item #	Description	Material	Thk [mm]	Length [mm]	Width [mm]	Weight [kg]	Qty
Plate1	End Plates	SA-516 70	12	152.4	342.9	4.9	2
Plate2	End Plates	SA-516 70	12	190.5	431.8	7.7	2
Plate3	Stay Plates	SA-516 70	12	3,276.6	152.4	46.9	1
Plate4	Stay Plates	SA-516 70	12	3,276.6	190.5	58.7	1
Plate5	Top / Bottom Plate	SA-516 70	15.88	3,300.6	152.4	62.5	2
Plate6	Top / Bottom Plate	SA-516 70	15.88	3,300.6	190.5	78.2	2
Plate7	Tubesheet / Plugsheet	SA-516 70	25.4	3,300.6	374.65	246	2
Plate8	Tubesheet / Plugsheet	SA-516 70	25.4	3,300.6	463.55	304.4	2

Tubes							
Item #	Type	Material	Thk [mm]	Dia [mm]	Length [mm]	Weight [kg] (ea)	Qty
Tube1	Tube	SA-179 Smls Tube	3.18	25.4	2,590.8	4.5	225

Inlet/Outlet Header

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Appendix 13 Plug Header		
		Design Pressure (bar)	Design Temperature (°C)	Design MDMT (°C)
Internal		6.89	343.33	-28.89
External		1.03	343.33	
Dimensions				
Tubesheet	Inside Length, h	431.8 mm		
	Thickness, t_2	25.4 mm		
Top/Bottom	Inside Length, H	190.5 mm		
	Thickness, t_1	15.88 mm		
End Plate Thickness, t_5		12 mm		
Length, L_v		3,276.6 mm		
Corrosion	Inner	0 mm		
	Outer	0 mm		
Tubes				
Number of Passes		2		
Pitch		76.2 mm		
Layout Angle		Rotated Triangular (60°)		
Quantity		225		
OD		25.4 mm		
Wall Thickness		3.18 mm		
Min Wall Thickness		2.78 mm		
Distance Between Headers		2,540 mm		
Corrosion	Inner	0 mm		
	Outer	0 mm		
Stay Plate				
Number of Stays		1		
Thickness, t_3		12 mm		
Maximum Compartment Dimension		203.2 mm		
Stay to End Plate Weld Full Penetration		✔		

Joint Efficiency	
Tubesheet/Plugsheet mid-plate	1
Top/Bottom mid-plate	1
Corner	1
End	1
Stay	1

Ligament Efficiency	
	Diameter, d
Tubesheet	25.65 mm
Plugsheet	26.3 mm

Material Summary					
Plate	**Material**	**Impact Tested**	**Normalized**	**Fine Grain Practice**	**PWHT**
Tubesheet/Plugsheet	SA-516 70	✘	✘	✘	✔
Top/Bottom	SA-516 70	✘	✘	✘	✔
End	SA-516 70	✘	✘	✘	✔
Stay	SA-516 70	✘	✘	✘	✔
Tubes	SA-179 Smls Tube	✘	✘	✘	✘

Results Summary					
	t (mm)	**t_d (mm)**	**MAWP (bar)**	**MAP (bar)**	**MDMT (°C)**
Tubesheet	25.4	10.91	34.26	36.65	-48
Plugsheet	25.4	10.98	33.82	36.18	-48
Top/Bottom	15.88	8.23	24.38	26.08	-40.25
Stay	12	1.12	74.19	79.37	-105

Stress Summary												
		S_m (kg_f/cm^2)	$S_{m,allow}$ (kg_f/cm^2)	$(S_b)_{N,M}$ (kg_f/cm^2)		$(S_b)_Q$ (kg_f/cm^2)		$(S_T)_{N,M}$ (kg_f/cm^2)		$(S_T)_Q$ (kg_f/cm^2)		$S_{T,allow}$ (kg_f/cm^2)
				Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	
Tubesheet	**Oper Hot & Corr**	40	1,315	357	-357	201	-201	397	-318	241	-161	1,973
	Shop Test New	174	2,404	1,564	-1,564	879	-879	1,738	-1,390	1,053	-705	3,607
Plugsheet	**Oper Hot & Corr**	40	1,315	362	-362	201	-201	402	-322	241	-161	1,973
	Shop Test New	176	2,404	1,584	-1,584	879	-879	1,760	-1,408	1,055	-703	3,607
Top/Bottom	**Oper Hot & Corr**	44	1,315	-245	245	514	-514	-201	289	558	-470	1,973
	Shop Test New	192	2,404	-1,072	1,072	2,250	-2,250	-881	1,264	2,442	-2,059	3,607
Stay	**Oper Hot & Corr**	122	1,315	-	-	-	-	122				1,315
	Shop Test New	535	2,404	-	-	-	-	535				2,404

UCS-66 Material Toughness Requirements Tubesheet	
Governing thickness, t_g =	15.88 mm
Exemption temperature from Fig UCS-66M Curve B =	-15.05°C
Stress ratio per UCS-66(b)(1)(b) $= \frac{22.26}{36.65} =$	0.6072
Reduction in MDMT, T_R from Fig UCS-66.1M =	22°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
$MDMT = \max[MDMT - T_R - T_{PWHT}, -48] = \max[-15.05 - 22 - 17, -48] =$	-48°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

UCS-66 Material Toughness Requirements Plugsheet	
Governing thickness, t_g =	15.88 mm
Exemption temperature from Fig UCS-66M Curve B =	-15.05°C
Stress ratio per UCS-66(b)(1)(b) $= \frac{22.26}{36.18} =$	0.6151
Reduction in MDMT, T_R from Fig UCS-66.1M =	21.6°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
$MDMT = \max[MDMT - T_R - T_{PWHT}, -48] = \max[-15.05 - 21.6 - 17, -48] =$	-48°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

UCS-66 Material Toughness Requirements Top/Bottom	
Governing thickness, t_g =	15.88 mm
Exemption temperature from Fig UCS-66M Curve B =	-15.05°C
Stress ratio per UCS-66(b)(1)(b) $= \frac{22.26}{26.08} =$	0.8534
Reduction in MDMT, T_R from Fig UCS-66.1M =	8.2°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
$MDMT = \max[MDMT - T_R - T_{PWHT}, -48] = \max[-15.05 - 8.2 - 17, -48] =$	-40.25°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

UCS-66 Material Toughness Requirements Stay	
Stress ratio per UCS-66$(b)(1)(b)$ $= \frac{22.26}{79.37} =$	0.2804
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

Vessel Parameters	
Aspect Ratio $= \frac{L_v}{h}$	
Aspect Ratio $= \frac{L_v}{H}$	
$I_1 = \frac{t_1^3}{12}$	
$I_2 = \frac{t_2^3}{12}$	
$\alpha = \frac{H}{h}$	
$K = \left(\frac{I_2}{I_1}\right)\alpha$	
New / Corroded	
Aspect Ratio $= \frac{3{,}276.6}{203.2} =$	16.125
Aspect Ratio $= \frac{3{,}276.6}{190.5} =$	17.2
$I_1 = \frac{15.88^{\ 3}}{12} =$	333.3957 mm^3
$I_2 = \frac{25.4^{\ 3}}{12} =$	1,365.5887 mm^3
$\alpha = \frac{190.5}{203.2} =$	0.9375
$K = \left(\frac{1{,}365.5887}{333.3957}\right) \cdot 0.9375 =$	3.84

Tubesheet
$e_m = e_b = \frac{p-d}{p}$
$S_{ml} = P\frac{H}{2t_2E_m}$
$(S_b)_{Mi} = Ph^2\frac{c_i}{12I_2E_b}\left[\frac{1+K\left(3-\alpha^2\right)}{1+2K}\right]$
$(S_b)_{Mo} = Ph^2\frac{c_o}{12I_2E_b}\left[\frac{1+K\left(3-\alpha^2\right)}{1+2K}\right]$
$(S_{bl})_{Qi} = Ph^2\frac{c_i}{12I_2E_b}\frac{1+2\alpha^2K}{1+2K}$

$(S_{tl})_{Qo} = P h^2 \frac{c_o}{12 I_2 E_b} \frac{1+2\alpha^2 K}{1+2K}$		
$(S_T)_{Mi} = S_{ml} + (S_b)_{Mi}$		
$(S_T)_{Mo} = S_{ml} + (S_b)_{Mo}$		
$(S_{Tl})_{Qi} = S_{ml} + (S_{tl})_{Qi}$		
$(S_{Tl})_{Qo} = S_{ml} + (S_{tl})_{Qo}$		
Ligament Efficiency		
$e_m = e_b = \frac{76.2-25.65}{76.2} =$	0.6634	
Plate Parameters		
New / Corroded		
$c_i = \frac{25.4-0-0}{2} =$	12.7 mm	
$c_o = -\frac{25.4-0-0}{2} =$	-12.7 mm	
Operating Hot & Corroded		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ml} = 6.89 \cdot 1.02 \cdot \frac{190.5}{2 \cdot 25.4 \cdot 0.6634} =$	39.743	1,315.434
$(S_b)_{Mi} = 6.89 \cdot 1.02 \cdot 203.2^2 \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6634} \cdot \left[\frac{1+3.84 \cdot (3-0.9375^2)}{1+2 \cdot 3.84}\right] =$	357.311	1,973.151
$(S_b)_{Mo} = 6.89 \cdot 1.02 \cdot 203.2^2 \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6634} \cdot \left[\frac{1+3.84 \cdot (3-0.9375^2)}{1+2 \cdot 3.84}\right] =$	-357.311	1,973.151
$(S_{tl})_{Qi} = 6.89 \cdot 1.02 \cdot 203.2^2 \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1+2 \cdot 0.9375^2 \cdot 3.84}{1+2 \cdot 3.84} =$	200.877	1,973.151
$(S_{tl})_{Qo} = 6.89 \cdot 1.02 \cdot 203.2^2 \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1+2 \cdot 0.9375^2 \cdot 3.84}{1+2 \cdot 3.84} =$	-200.877	1,973.151
$(S_T)_{Mi} = 39.743 + 357.311 =$	397.054	1,973.151
$(S_T)_{Mo} = 39.743 + -357.311 =$	-317.568	1,973.151
$(S_{Tl})_{Qi} = 39.743 + 200.877 =$	240.62	1,973.151
$(S_{Tl})_{Qo} = 39.743 + -200.877 =$	-161.134	1,973.151
Shop Test New		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ml} = 30.17 \cdot 1.02 \cdot \frac{190.5}{2 \cdot 25.4 \cdot 0.6634} =$	173.926	2,404.491
$(S_b)_{Mi} = 30.17 \cdot 1.02 \cdot 203.2^2 \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6634} \cdot \left[\frac{1+3.84 \cdot (3-0.9375^2)}{1+2 \cdot 3.84}\right] =$	1,563.679	3,606.736
$(S_b)_{Mo} = 30.17 \cdot 1.02 \cdot 203.2^2 \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6634} \cdot \left[\frac{1+3.84 \cdot (3-0.9375^2)}{1+2 \cdot 3.84}\right] =$	-1,563.679	3,606.736

$(S_{tl})_{Qi} = 30.17 \cdot 1.02 \cdot 203.2^{\ 2} \cdot \dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9375^{\ 2} \cdot 3.84}{1 + 2 \cdot 3.84} =$	879.087	3,606.736
$(S_{tl})_{Qo} = 30.17 \cdot 1.02 \cdot 203.2^{\ 2} \cdot -\dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9375^{\ 2} \cdot 3.84}{1 + 2 \cdot 3.84} =$	-879.087	3,606.736
$(S_T)_{Mi} = 173.926 + 1{,}563.679 =$	1,737.605	3,606.736
$(S_T)_{Mo} = 173.926 + -1{,}563.679 =$	-1,389.753	3,606.736
$(S_{Tl})_{Qi} = 173.926 + 879.087 =$	1,053.013	3,606.736
$(S_{Tl})_{Qo} = 173.926 + -879.087 =$	-705.161	3,606.736

Plugsheet		
$e_m = e_b = \dfrac{p-d}{p}$		
$S_{ml} = P\dfrac{H}{2t_2E_m}$		
$(S_b)_{Mi} = Ph^2\dfrac{c_i}{12I_2E_b}\left[\dfrac{1+K\left(3-\alpha^2\right)}{1+2K}\right]$		
$(S_b)_{Mo} = Ph^2\dfrac{c_o}{12I_2E_b}\left[\dfrac{1+K\left(3-\alpha^2\right)}{1+2K}\right]$		
$(S_{tl})_{Qi} = Ph^2\dfrac{c_i}{12I_2E_b}\dfrac{1+2\alpha^2K}{1+2K}$		
$(S_{tl})_{Qo} = Ph^2\dfrac{c_o}{12I_2E_b}\dfrac{1+2\alpha^2K}{1+2K}$		
$(S_T)_{Mi} = S_{ml} + (S_b)_{Mi}$		
$(S_T)_{Mo} = S_{ml} + (S_b)_{Mo}$		
$(S_{Tl})_{Qi} = S_{ml} + (S_{tl})_{Qi}$		
$(S_{Tl})_{Qo} = S_{ml} + (S_{tl})_{Qo}$		
Ligament Efficiency		
$e_m = e_b = \dfrac{76.2-26.3}{76.2} =$	0.6549	
Plate Parameters		
New / Corroded		
$c_i = \dfrac{25.4-0-0}{2} =$	12.7 mm	
$c_o = -\dfrac{25.4-0-0}{2} =$	-12.7 mm	
Operating Hot & Corroded		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ml} = 6.89 \cdot 1.02 \cdot \dfrac{190.5}{2 \cdot 25.4 \cdot 0.6549} =$	40.261	1,315.434

$(S_b)_{Mi} = 6.89 \cdot 1.02 \cdot 203.2^{\,2} \cdot \dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6549} \cdot \left[\dfrac{1 + 3.84 \cdot (3 - 0.9375^{\,2})}{1 + 2 \cdot 3.84}\right] =$	361.965	1,973.151
$(S_b)_{Mo} = 6.89 \cdot 1.02 \cdot 203.2^{\,2} \cdot -\dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6549} \cdot \left[\dfrac{1 + 3.84 \cdot (3 - 0.9375^{\,2})}{1 + 2 \cdot 3.84}\right] =$	-361.965	1,973.151
$(S_{bl})_{Qi} = 6.89 \cdot 1.02 \cdot 203.2^{\,2} \cdot \dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9375^{\,2} \cdot 3.84}{1 + 2 \cdot 3.84} =$	200.877	1,973.151
$(S_{bl})_{Qo} = 6.89 \cdot 1.02 \cdot 203.2^{\,2} \cdot -\dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9375^{\,2} \cdot 3.84}{1 + 2 \cdot 3.84} =$	-200.877	1,973.151
$(S_T)_{Mi} = 40.261 + 361.965 =$	402.226	1,973.151
$(S_T)_{Mo} = 40.261 + -361.965 =$	-321.704	1,973.151
$(S_{Tl})_{Qi} = 40.261 + 200.877 =$	241.138	1,973.151
$(S_{Tl})_{Qo} = 40.261 + -200.877 =$	-160.616	1,973.151
Shop Test New		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ml} = 30.17 \cdot 1.02 \cdot \dfrac{190.5}{2 \cdot 25.4 \cdot 0.6549} =$	176.192	2,404.491
$(S_b)_{Mi} = 30.17 \cdot 1.02 \cdot 203.2^{\,2} \cdot \dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6549} \cdot \left[\dfrac{1 + 3.84 \cdot (3 - 0.9375^{\,2})}{1 + 2 \cdot 3.84}\right] =$	1,584.047	3,606.736
$(S_b)_{Mo} = 30.17 \cdot 1.02 \cdot 203.2^{\,2} \cdot -\dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6549} \cdot \left[\dfrac{1 + 3.84 \cdot (3 - 0.9375^{\,2})}{1 + 2 \cdot 3.84}\right] =$	-1,584.047	3,606.736
$(S_{bl})_{Qi} = 30.17 \cdot 1.02 \cdot 203.2^{\,2} \cdot \dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9375^{\,2} \cdot 3.84}{1 + 2 \cdot 3.84} =$	879.087	3,606.736
$(S_{bl})_{Qo} = 30.17 \cdot 1.02 \cdot 203.2^{\,2} \cdot -\dfrac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9375^{\,2} \cdot 3.84}{1 + 2 \cdot 3.84} =$	-879.087	3,606.736
$(S_T)_{Mi} = 176.192 + 1{,}584.047 =$	1,760.239	3,606.736
$(S_T)_{Mo} = 176.192 + -1{,}584.047 =$	-1,407.856	3,606.736
$(S_{Tl})_{Qi} = 176.192 + 879.087 =$	1,055.278	3,606.736
$(S_{Tl})_{Qo} = 176.192 + -879.087 =$	-702.895	3,606.736

Top/Bottom
$S_{ms} = P \dfrac{h}{4 t_1 E_m} \left\{ 4 - \left[\dfrac{2 + K(5 - \alpha^2)}{1 + 2K} \right] \right\}$
$(S_b)_{Ni} = P \dfrac{c_i}{24 I_1 E_b} \left[-3H^2 + 2h^2 \dfrac{1 + 2\alpha^2 K}{1 + 2K} \right]$
$(S_b)_{No} = P \dfrac{c_o}{24 I_1 E_b} \left[-3H^2 + 2h^2 \dfrac{1 + 2\alpha^2 K}{1 + 2K} \right]$
$(S_{bs})_{Qi} = P h^2 \dfrac{c_i}{12 I_1 E_b} \dfrac{1 + 2\alpha^2 K}{1 + 2K}$

$(S_{bs})_{Qo} = Ph^2 \frac{c_o}{12 I_1 E_b} \frac{1+2\alpha^2 K}{1+2K}$		
$(S_T)_{Ni} = S_{ms} + (S_b)_{Ni}$		
$(S_T)_{No} = S_{ms} + (S_b)_{No}$		
$(S_{Ts})_{Qi} = S_{ms} + (S_{bs})_{Qi}$		
$(S_{Ts})_{Qo} = S_{ms} + (S_{bs})_{Qo}$		
Plate Parameters		
New / Corroded		
$c_i = \frac{15.88 - 0 - 0}{2} =$	7.94 mm	
$c_o = -\frac{15.88 - 0 - 0}{2} =$	-7.94 mm	
Operating Hot & Corroded		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ms} = 6.89 \cdot 1.02 \cdot \frac{203.2}{4 \cdot 15.88 \cdot 1} \cdot \left\{4 - \left[\frac{2 + 3.84 \cdot (5 - 0.9375^2)}{1 + 2 \cdot 3.84}\right]\right\} =$	43.791	1,315.434
$(S_b)_{Ni} = 6.89 \cdot 1.02 \cdot \frac{7.94}{24 \cdot 333.3957 \cdot 1} \cdot \left[-3 \cdot 190.5^2 + 2 \cdot 203.2^2 \cdot \frac{1 + 2 \cdot 0.9375^2 \cdot 3.84}{1 + 2 \cdot 3.84}\right] =$	-245.07	1,973.151
$(S_b)_{No} = 6.89 \cdot 1.02 \cdot -\frac{7.94}{24 \cdot 333.3957 \cdot 1} \cdot \left[-3 \cdot 190.5^2 + 2 \cdot 203.2^2 \cdot \frac{1 + 2 \cdot 0.9375^2 \cdot 3.84}{1 + 2 \cdot 3.84}\right] =$	245.07	1,973.151
$(S_{bs})_{Qi} = 6.89 \cdot 1.02 \cdot 203.2^2 \cdot \frac{7.94}{12 \cdot 333.3957 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9375^2 \cdot 3.84}{1 + 2 \cdot 3.84} =$	514.245	1,973.151
$(S_{bs})_{Qo} = 6.89 \cdot 1.02 \cdot 203.2^2 \cdot -\frac{7.94}{12 \cdot 333.3957 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9375^2 \cdot 3.84}{1 + 2 \cdot 3.84} =$	-514.245	1,973.151
$(S_T)_{Ni} = 43.791 + -245.07 =$	-201.279	1,973.151
$(S_T)_{No} = 43.791 + 245.07 =$	288.861	1,973.151
$(S_{Ts})_{Qi} = 43.791 + 514.245 =$	558.036	1,973.151
$(S_{Ts})_{Qo} = 43.791 + -514.245 =$	-470.454	1,973.151
Shop Test New		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ms} = 30.17 \cdot 1.02 \cdot \frac{203.2}{4 \cdot 15.88 \cdot 1} \cdot \left\{4 - \left[\frac{2 + 3.84 \cdot (5 - 0.9375^2)}{1 + 2 \cdot 3.84}\right]\right\} =$	191.641	2,404.491
$(S_b)_{Ni} = 30.17 \cdot 1.02 \cdot \frac{7.94}{24 \cdot 333.3957 \cdot 1} \cdot \left[-3 \cdot 190.5^2 + 2 \cdot 203.2^2 \cdot \frac{1 + 2 \cdot 0.9375^2 \cdot 3.84}{1 + 2 \cdot 3.84}\right] =$	-1,072.486	3,606.736
$(S_b)_{No} = 30.17 \cdot 1.02 \cdot -\frac{7.94}{24 \cdot 333.3957 \cdot 1} \cdot \left[-3 \cdot 190.5^2 + 2 \cdot 203.2^2 \cdot \frac{1 + 2 \cdot 0.9375^2 \cdot 3.84}{1 + 2 \cdot 3.84}\right] =$	1,072.486	3,606.736
$(S_{bs})_{Qi} = 30.17 \cdot 1.02 \cdot 203.2^2 \cdot \frac{7.94}{12 \cdot 333.3957 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9375^2 \cdot 3.84}{1 + 2 \cdot 3.84} =$	2,250.462	3,606.736

$(S_{bs})_{Qo} = 30.17 \cdot 1.02 \cdot 203.2^{\ 2} \cdot -\dfrac{7.94}{12 \cdot 333.3957 \cdot 1} \cdot \dfrac{1+2 \cdot 0.9375^{\ 2} \cdot 3.84}{1+2 \cdot 3.84} =$	-2,250.462	3,606.736
$(S_T)_{Ni} = 191.641 + -1{,}072.486 =$	-880.845	3,606.736
$(S_T)_{No} = 191.641 + 1{,}072.486 =$	1,264.127	3,606.736
$(S_{Ts})_{Qi} = 191.641 + 2{,}250.462 =$	2,442.103	3,606.736
$(S_{Ts})_{Qo} = 191.641 + -2{,}250.462 =$	-2,058.821	3,606.736

Stay		
$S_{mst} = P\dfrac{h}{2t_3E_{st}}\left[\dfrac{2+K\left(5-\alpha^2\right)}{1+2K}\right]$		
Operating Hot & Corroded		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{mst} = 6.89 \cdot 1.02 \cdot \dfrac{203.2}{2 \cdot 12 \cdot 1} \cdot \left[\dfrac{2+3.84 \cdot \left(5-0.9375^{\ 2}\right)}{1+2 \cdot 3.84}\right] =$	122.242	1,315.434
Shop Test New		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{mst} = 30.17 \cdot 1.02 \cdot \dfrac{203.2}{2 \cdot 12 \cdot 1} \cdot \left[\dfrac{2+3.84 \cdot \left(5-0.9375^{\ 2}\right)}{1+2 \cdot 3.84}\right] =$	534.961	2,404.491

Tubes

ASME Section VIII Division 1, 2021 Edition Metric					
Component		Tube			
Material		SA-179 Smls Tube (II-D Metric p. 8, ln. 11)			
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**		
No	No	No	No		
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**	
Internal		6.89	343.33	-28.89	
External		1.03	343.33		
Dimensions					
Outer Diameter		25.4 mm			
Length		2,590.8 mm			
Tube Nominal Thickness		3.18 mm			
Tube Minimum Thickness[1]		2.78 mm			
Corrosion	**Inner**	0 mm			
	Outer	0 mm			
Weight and Capacity					
		Weight (kg)		**Capacity (liters)**	
New		4.5		0.74	
Corroded		4.5		0.74	

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

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	Exempt per UG-16(b)(2)
Design thickness due to internal pressure (t)	0.1 mm
Design thickness due to external pressure (t_e)	0.22 mm
Maximum allowable working pressure (MAWP)	212.4 bar
Maximum allowable pressure (MAP)	221.51 bar
Maximum allowable external pressure (MAEP)	114.25 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
Impact test exempt per UCS-66(d) (NPS 4 or smaller pipe) =	-105°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

Design thickness, (at 343.33 °C) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{6.89 \cdot 12.7}{886 \cdot 1.00 + 0.40 \cdot 6.89} + 0 = 0.1 \text{ mm}$$

Maximum allowable working pressure, (at 343.33 °C) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{886 \cdot 1.00 \cdot (3.18 \cdot 0.875)}{12.7 - 0.40 \cdot (3.18 \cdot 0.875)} - 0 = 212.4 \text{ bar}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{924 \cdot 1.00 \cdot (3.18 \cdot 0.875)}{12.7 - 0.40 \cdot (3.18 \cdot 0.875)} = 221.51 \text{ bar}$$

External Pressure, (Corroded & at 343.33 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{2{,}590.8}{25.4} = 50.0000$$

$$\frac{D_o}{t} = \frac{25.4}{0.22} = 117.3116$$

From table G: $A = 0.000083$

From table CS-1 Metric: $B = 92.7809 \ \ \text{kg/cm}^{\ 2} (90.99 \ \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 90.99}{3 \cdot (25.4/0.22)} = 1.03 \ \ \text{bar}$$

Design thickness for external pressure P_a = 1.03 bar

$t_a = t + \text{Corrosion} = 0.22 + 0 = 0.22$ mm

Maximum Allowable External Pressure, (Corroded & at 343.33 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{2{,}590.8}{25.4} = 50.0000$$

$$\frac{D_o}{t} = \frac{25.4}{3.18 \text{-} 0.875} = 9.1429$$

From table G: $A = 0.013800$

From table CS-1 Metric: $B = 757.9092 \ \ \text{kg/cm}^{\ 2} (743.2537 \ \ \text{bar})$

$$S_y = 2 \cdot B_{sy} = 2 \cdot 806.4497 = 1{,}612.9 \ \ \text{kg/cm}^{\ 2}$$

$$S_1 = 2 \cdot S_e = 2 \cdot 903.5 = 1{,}806.9 \ \ \text{kg/cm}^{\ 2}$$

$$S_2 = 0.90 \cdot S_y = 0.90 \cdot 1{,}612.9 = 1{,}451.6 \ \ \text{kg/cm}^{\ 2}$$

$$S = \min\,(S_1, S_2) = \min\,(1{,}806.9, 1{,}451.6) = 1{,}451.6 \ \ \text{kg/cm}^{\ 2}$$

$$P_{a1} = \left[\frac{2.167}{D_o/t} - 0.08333\right] \cdot B = \left[\frac{2.167}{9.1429} - 0.08333\right] \cdot 757.9 = 114.25 \ \ \text{bar}$$

$$P_{a2} = \left(\frac{2 \cdot S}{D_o/t}\right) \cdot \left[1 - \frac{1}{D_o/t}\right] = \left(2 \cdot \frac{1{,}451.6}{9.1429}\right) \cdot \left[1 - \frac{1}{9.1429}\right] = 277.34 \ \ \text{bar}$$

Maximum Allowable External Pressure = min(P_{a1}, P_{a2}) = 114.25 bar

End Plates for Inlet/Outlet Header

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Appendix 13 End Plate		
Material		SA-516 70 (II-D Metric p. 20, ln. 45)		
Impact Tested	Normalized	Fine Grain Practice	PWHT	
No	No	No	Yes	
		Design Pressure (bar)	Design Temperature (°C)	Design MDMT (°C)
Internal		6.89	343.33	-28.89
External		1.03	343.33	
Static Liquid Head				
Condition		P_s (bar)	H_s (mm)	SG
Test horizontal		0.04	431.8	1
Dimensions				
Short Inside Length (d)		190.5 mm		
Long Inside Length (D)		203.2 mm		
Nominal Thickness		12 mm		
Corrosion	Inner	0 mm		
	Outer	0 mm		
Joint Efficiency		1		

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	1.5 mm + 0 mm = 1.5 mm
Design thickness due to internal pressure (t)	6.68 mm
Design thickness due to external pressure (t_e)	2.59 mm
Maximum allowable working pressure (MAWP)	22.26 bar
Maximum allowable pressure (MAP)	23.81 bar
Maximum allowable external pressure (MAEP)	22.26 bar
Rated MDMT	-44.01°C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	12 mm
Exemption temperature from Fig UCS-66M Curve B =	-23.31°C
$\text{Stress ratio per UCS-66}(b)(1)(b) = \frac{22.26}{23.81} =$	0.9348
Reduction in MDMT, T_R from Fig UCS-66.1M =	3.7°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
$MDMT = \max\left[MDMT - T_R - T_{PWHT}, -48\right] = \max\left[-23.31 - 3.7 - 17, -48\right] =$	-44.01°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

Factor C from Appendix 13-4(f)

$\text{Factor} \quad C = 0.2$

Factor Z

$$Z = \min\left[3.4 - \frac{2.4 \cdot d}{D}, 2.5\right] = \min\left[3.4 - \frac{2.4 \cdot d}{203.2}, 2.5\right] = 1.15$$

Design thickness, (at 343.33 °C) UG-34(c)(3)

$$t = d \cdot \sqrt{\frac{Z \cdot C \cdot P \cdot 1.02}{S \cdot E}} + \text{Corrosion} = 190.5 \cdot \sqrt{\frac{1.15 \cdot 0.2 \cdot 6.89 \cdot 1.02}{1{,}315.434 \cdot 1}} + 0 = 6.68 \text{ mm}$$

Maximum allowable working pressure, (at 343.33 °C)

$$MAWP = \left(\frac{S \cdot E}{C \cdot Z}\right) \cdot \left(\frac{t}{d}\right)^2 - P_s = \left(\frac{\frac{1{,}315.434}{1.02} \cdot 1}{0.2 \cdot 1.15}\right) \cdot \left(\frac{12}{190.5}\right)^2 - 0 = 22.26 \text{ bar}$$

Maximum allowable pressure, (At 21.11 °C)

$$Z = \min\left[3.4 - \frac{2.4 \cdot d}{D}, 2.5\right] = \min\left[3.4 - \frac{2.4 \cdot d}{203.2}, 2.5\right] = 1.15$$

$$MAP = \left(\frac{S \cdot E}{C \cdot Z}\right) \cdot \left(\frac{t}{d}\right)^2 = \left(\frac{\frac{1{,}407.208}{1.02} \cdot 1}{0.2 \cdot 1.15}\right) \cdot \left(\frac{12}{190.5}\right)^2 = 23.81 \text{ bar}$$

Design thickness for external pressure, (at 343.33 °C) UG-34(c)(3)

$$t = d \cdot \sqrt{\frac{Z \cdot C \cdot P_e \cdot 1.02}{S \cdot E}} + \text{Corrosion} = 190.5 \cdot \sqrt{\frac{1.15 \cdot 0.2 \cdot 1.03 \cdot 1.02}{1{,}315.434 \cdot 1}} + 0 = 2.59 \text{ mm}$$

Maximum allowable external pressure, (At 343.33 °C)

$$\text{MAEP} = \left(\frac{S \cdot E}{C \cdot Z}\right) \cdot \left(\frac{t}{d}\right)^2 = \left(\frac{\frac{1{,}315.434}{1.02} \cdot 1}{0.2 \cdot 1.15}\right) \cdot \left(\frac{12}{190.5}\right)^2 = 22.26 \text{ bar}$$

Return Header

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Appendix 13 Plug Header		
		Design Pressure (bar)	Design Temperature (°C)	Design MDMT (°C)
Internal		6.89	343.33	-28.89
External		1.03	343.33	
Dimensions				
Tubesheet	Inside Length, h	342.9 mm		
	Thickness, t_2	25.4 mm		
Top/Bottom	Inside Length, H	152.4 mm		
	Thickness, t_1	15.88 mm		
End Plate Thickness, t_5		12 mm		
Length, L_v		3,276.6 mm		
Corrosion	Inner	0 mm		
	Outer	0 mm		
Tubes				
Number of Passes		2		
Pitch		76.2 mm		
Layout Angle		Rotated Triangular (60°)		
Quantity		225		
OD		25.4 mm		
Wall Thickness		3.18 mm		
Min Wall Thickness		2.78 mm		
Distance Between Headers		2,540 mm		
Corrosion	Inner	0 mm		
	Outer	0 mm		
Stay Plate				
Number of Stays		1		
Thickness, t_3		12 mm		
Maximum Compartment Dimension		165.1 mm		
Stay to End Plate Weld Full Penetration		✔		

Joint Efficiency	
Tubesheet/Plugsheet mid-plate	1
Top/Bottom mid-plate	1
Corner	1
End	1
Stay	1

Ligament Efficiency	
	Diameter, d
Tubesheet	25.65 mm
Plugsheet	26.3 mm

Material Summary					
Plate	**Material**	**Impact Tested**	**Normalized**	**Fine Grain Practice**	**PWHT**
Tubesheet/Plugsheet	SA-516 70	✘	✘	✘	✔
Top/Bottom	SA-516 70	✘	✘	✘	✔
End	SA-516 70	✘	✘	✘	✔
Stay	SA-516 70	✘	✘	✘	✔
Tubes	SA-179 Smls Tube	✘	✘	✘	✘

Results Summary					
	t (mm)	**t_d (mm)**	**MAWP (bar)**	**MAP (bar)**	**MDMT (°C)**
Tubesheet	25.4	8.84	50.33	53.84	-48
Plugsheet	25.4	8.9	49.68	53.15	-48
Top/Bottom	15.88	6.58	37.18	39.77	-48
Stay	12	0.91	90.8	97.13	-105

Stress Summary												
		S_m (kg_f/ cm^2)	$S_{m,allow}$ (kg_f/ cm^2)	$(S_b)_{N,M}$ (kg_f/ cm^2)		$(S_b)_Q$ (kg_f/ cm^2)		$(S_T)_{N,M}$ (kg_f/ cm^2)		$(S_T)_Q$ (kg_f/ cm^2)		$S_{T,allow}$ (kg_f/ cm^2)
				Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	
Tubesheet	Oper Hot & Corr	32	1,315	239	-239	129	-129	270	-207	161	-97	1,973
	Shop Test New	139	2,404	1,044	-1,044	565	-565	1,183	-905	704	-426	3,607
Plugsheet	Oper Hot & Corr	32	1,315	242	-242	129	-129	274	-209	161	-97	1,973
	Shop Test New	141	2,404	1,057	-1,057	565	-565	1,198	-916	706	-424	3,607
Top/Bottom	Oper Hot & Corr	35	1,315	-155	155	331	-331	-120	191	366	-295	1,973
	Shop Test New	155	2,404	-680	680	1,447	-1,447	-525	835	1,601	-1,292	3,607
Stay	Oper Hot & Corr	100	1,315	-	-	-	-	100				1,315
	Shop Test New	437	2,404	-	-	-	-	437				2,404

UCS-66 Material Toughness Requirements Tubesheet	
Governing thickness, t_g =	15.88 mm
Exemption temperature from Fig UCS-66M Curve B =	-15.05°C
Stress ratio per UCS-66(b)(1)(b) $= \frac{22.26}{53.84} =$	0.4134
Reduction in MDMT, T_R from Fig UCS-66.1M =	47.4°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
$MDMT = \max\left[MDMT - T_R - T_{PWHT}, -48\right] = \max\left[-15.05 - 47.4 - 17, -48\right] =$	-48°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

UCS-66 Material Toughness Requirements Plugsheet	
Governing thickness, t_g =	15.88 mm
Exemption temperature from Fig UCS-66M Curve B =	-15.05°C
Stress ratio per UCS-66(b)(1)(b) $= \frac{22.26}{53.15} =$	0.4187
Reduction in MDMT, T_R from Fig UCS-66.1M =	45.9°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
$MDMT = \max\left[MDMT - T_R - T_{PWHT}, -48\right] = \max\left[-15.05 - 45.9 - 17, -48\right] =$	-48°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

UCS-66 Material Toughness Requirements Top/Bottom	
Governing thickness, t_g =	15.88 mm
Exemption temperature from Fig UCS-66M Curve B =	-15.05°C
Stress ratio per UCS-66(b)(1)(b) $= \frac{22.26}{39.77} =$	0.5596
Reduction in MDMT, T_R from Fig UCS-66.1M =	26.2°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
$MDMT = \max\left[MDMT - T_R - T_{PWHT}, -48\right] = \max\left[-15.05 - 26.2 - 17, -48\right] =$	-48°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

UCS-66 Material Toughness Requirements Stay	
Stress ratio per UCS-66$(b)(1)(b) = \frac{22.26}{97.13} =$	0.2291
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

Vessel Parameters	
$\text{Aspect Ratio} = \frac{L_v}{h}$	
$\text{Aspect Ratio} = \frac{L_v}{H}$	
$I_1 = \frac{t_1^3}{12}$	
$I_2 = \frac{t_2^3}{12}$	
$\alpha = \frac{H}{h}$	
$K = \left(\frac{I_2}{I_1}\right)\alpha$	
New / Corroded	
$\text{Aspect Ratio} = \frac{3{,}276.6}{165.1} =$	19.8462
$\text{Aspect Ratio} = \frac{3{,}276.6}{152.4} =$	21.5
$I_1 = \frac{15.88^{\ 3}}{12} =$	333.3957 mm^3
$I_2 = \frac{25.4^{\ 3}}{12} =$	1,365.5887 mm^3
$\alpha = \frac{152.4}{165.1} =$	0.9231
$K = \left(\frac{1{,}365.5887}{333.3957}\right) \cdot 0.9231 =$	3.7809

Tubesheet
$e_m = e_b = \frac{p-d}{p}$
$S_{ml} = P\frac{H}{2t_2E_m}$
$(S_b)_{Mi} = Ph^2\frac{c_i}{12I_2E_b}\left[\frac{1+K\left(3-\alpha^2\right)}{1+2K}\right]$
$(S_b)_{Mo} = Ph^2\frac{c_o}{12I_2E_b}\left[\frac{1+K\left(3-\alpha^2\right)}{1+2K}\right]$
$(S_{bl})_{Qi} = Ph^2\frac{c_i}{12I_2E_b}\frac{1+2\alpha^2K}{1+2K}$

$(S_{bl})_{Qo} = Ph^2 \frac{c_o}{12 I_2 E_b} \frac{1+2\alpha^2 K}{1+2K}$		
$(S_T)_{Mi} = S_{ml} + (S_b)_{Mi}$		
$(S_T)_{Mo} = S_{ml} + (S_b)_{Mo}$		
$(S_{Tl})_{Qi} = S_{ml} + (S_{bl})_{Qi}$		
$(S_{Tl})_{Qo} = S_{ml} + (S_{bl})_{Qo}$		
Ligament Efficiency		
$e_m = e_b = \frac{76.2 - 25.65}{76.2} =$	0.6634	
Plate Parameters		
New / Corroded		
$c_i = \frac{25.4 - 0 - 0}{2} =$	12.7 mm	
$c_o = -\frac{25.4 - 0 - 0}{2} =$	-12.7 mm	
Operating Hot & Corroded		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ml} = 6.89 \cdot 1.02 \cdot \frac{152.4}{2 \cdot 25.4 \cdot 0.6634} =$	31.795	1,315.434
$(S_b)_{Mi} = 6.89 \cdot 1.02 \cdot 165.1^2 \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6634} \cdot \left[\frac{1 + 3.7809 \cdot (3 - 0.9231^2)}{1 + 2 \cdot 3.7809}\right] =$	238.513	1,973.151
$(S_b)_{Mo} = 6.89 \cdot 1.02 \cdot 165.1^2 \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6634} \cdot \left[\frac{1 + 3.7809 \cdot (3 - 0.9231^2)}{1 + 2 \cdot 3.7809}\right] =$	-238.513	1,973.151
$(S_{bl})_{Qi} = 6.89 \cdot 1.02 \cdot 165.1^2 \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	129.119	1,973.151
$(S_{bl})_{Qo} = 6.89 \cdot 1.02 \cdot 165.1^2 \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	-129.119	1,973.151
$(S_T)_{Mi} = 31.795 + 238.513 =$	270.307	1,973.151
$(S_T)_{Mo} = 31.795 + -238.513 =$	-206.718	1,973.151
$(S_{Tl})_{Qi} = 31.795 + 129.119 =$	160.913	1,973.151
$(S_{Tl})_{Qo} = 31.795 + -129.119 =$	-97.324	1,973.151
Shop Test New		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ml} = 30.17 \cdot 1.02 \cdot \frac{152.4}{2 \cdot 25.4 \cdot 0.6634} =$	139.141	2,404.491
$(S_b)_{Mi} = 30.17 \cdot 1.02 \cdot 165.1^2 \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6634} \cdot \left[\frac{1 + 3.7809 \cdot (3 - 0.9231^2)}{1 + 2 \cdot 3.7809}\right] =$	1,043.789	3,606.736
$(S_b)_{Mo} = 30.17 \cdot 1.02 \cdot 165.1^2 \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6634} \cdot \left[\frac{1 + 3.7809 \cdot (3 - 0.9231^2)}{1 + 2 \cdot 3.7809}\right] =$	-1,043.789	3,606.736

$(S_{bl})_{Qi} = 30.17 \cdot 1.02 \cdot 165.1^{\ 2} \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9231^{\ 2} \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	565.055	3,606.736
$(S_{bl})_{Qo} = 30.17 \cdot 1.02 \cdot 165.1^{\ 2} \cdot - \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9231^{\ 2} \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	-565.055	3,606.736
$(S_T)_{Mi} = 139.141 + 1{,}043.789 =$	1,182.93	3,606.736
$(S_T)_{Mo} = 139.141 + -1{,}043.789 =$	-904.648	3,606.736
$(S_{Tl})_{Qi} = 139.141 + 565.055 =$	704.196	3,606.736
$(S_{Tl})_{Qo} = 139.141 + -565.055 =$	-425.914	3,606.736

Plugsheet		
$e_m = e_b = \frac{p - d}{p}$		
$S_{ml} = P \frac{H}{2 t_2 E_m}$		
$(S_b)_{Mi} = Ph^2 \frac{c_i}{12 I_2 E_b} \left[\frac{1 + K \left(3 - \alpha^2\right)}{1 + 2K} \right]$		
$(S_b)_{Mo} = Ph^2 \frac{c_o}{12 I_2 E_b} \left[\frac{1 + K \left(3 - \alpha^2\right)}{1 + 2K} \right]$		
$(S_{bl})_{Qi} = Ph^2 \frac{c_i}{12 I_2 E_b} \frac{1 + 2\alpha^2 K}{1 + 2K}$		
$(S_{bl})_{Qo} = Ph^2 \frac{c_o}{12 I_2 E_b} \frac{1 + 2\alpha^2 K}{1 + 2K}$		
$(S_T)_{Mi} = S_{ml} + (S_b)_{Mi}$		
$(S_T)_{Mo} = S_{ml} + (S_b)_{Mo}$		
$(S_{Tl})_{Qi} = S_{ml} + (S_{bl})_{Qi}$		
$(S_{Tl})_{Qo} = S_{ml} + (S_{bl})_{Qo}$		
Ligament Efficiency		
$e_m = e_b = \frac{76.2 - 26.3}{76.2} =$	0.6549	
Plate Parameters		
New / Corroded		
$c_i = \frac{25.4 - 0 - 0}{2} =$	12.7 mm	
$c_o = -\frac{25.4 - 0 - 0}{2} =$	-12.7 mm	
Operating Hot & Corroded		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ml} = 6.89 \cdot 1.02 \cdot \frac{152.4}{2 \cdot 25.4 \cdot 0.6549} =$	32.209	1,315.434

$(S_b)_{Mi} = 6.89 \cdot 1.02 \cdot 165.1^{2} \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6549} \cdot \left[\frac{1 + 3.7809 \cdot (3 - 0.9231^{2})}{1 + 2 \cdot 3.7809}\right] =$	241.619	1,973.151
$(S_b)_{Mo} = 6.89 \cdot 1.02 \cdot 165.1^{2} \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6549} \cdot \left[\frac{1 + 3.7809 \cdot (3 - 0.9231^{2})}{1 + 2 \cdot 3.7809}\right] =$	-241.619	1,973.151
$(S_{tl})_{Qi} = 6.89 \cdot 1.02 \cdot 165.1^{2} \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9231^{2} \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	129.119	1,973.151
$(S_{tl})_{Qo} = 6.89 \cdot 1.02 \cdot 165.1^{2} \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9231^{2} \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	-129.119	1,973.151
$(S_T)_{Mi} = 32.209 + 241.619 =$	273.828	1,973.151
$(S_T)_{Mo} = 32.209 + -241.619 =$	-209.411	1,973.151
$(S_{Tl})_{Qi} = 32.209 + 129.119 =$	161.327	1,973.151
$(S_{Tl})_{Qo} = 32.209 + -129.119 =$	-96.91	1,973.151
Shop Test New		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ml} = 30.17 \cdot 1.02 \cdot \frac{152.4}{2 \cdot 25.4 \cdot 0.6549} =$	140.953	2,404.491
$(S_b)_{Mi} = 30.17 \cdot 1.02 \cdot 165.1^{2} \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6549} \cdot \left[\frac{1 + 3.7809 \cdot (3 - 0.9231^{2})}{1 + 2 \cdot 3.7809}\right] =$	1,057.385	3,606.736
$(S_b)_{Mo} = 30.17 \cdot 1.02 \cdot 165.1^{2} \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 0.6549} \cdot \left[\frac{1 + 3.7809 \cdot (3 - 0.9231^{2})}{1 + 2 \cdot 3.7809}\right] =$	-1,057.385	3,606.736
$(S_{tl})_{Qi} = 30.17 \cdot 1.02 \cdot 165.1^{2} \cdot \frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9231^{2} \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	565.055	3,606.736
$(S_{tl})_{Qo} = 30.17 \cdot 1.02 \cdot 165.1^{2} \cdot -\frac{12.7}{12 \cdot 1{,}365.5887 \cdot 1} \cdot \frac{1 + 2 \cdot 0.9231^{2} \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	-565.055	3,606.736
$(S_T)_{Mi} = 140.953 + 1{,}057.385 =$	1,198.339	3,606.736
$(S_T)_{Mo} = 140.953 + -1{,}057.385 =$	-916.432	3,606.736
$(S_{Tl})_{Qi} = 140.953 + 565.055 =$	706.008	3,606.736
$(S_{Tl})_{Qo} = 140.953 + -565.055 =$	-424.101	3,606.736

Top/Bottom
$S_{ms} = P\frac{h}{4t_1 E_m}\left\{4 - \left[\frac{2 + K\left(5 - \alpha^2\right)}{1 + 2K}\right]\right\}$
$(S_b)_{Ni} = P\frac{c_i}{24I_1E_b}\left[-3H^2 + 2h^2\frac{1 + 2\alpha^2K}{1 + 2K}\right]$
$(S_b)_{No} = P\frac{c_o}{24I_1E_b}\left[-3H^2 + 2h^2\frac{1 + 2\alpha^2K}{1 + 2K}\right]$
$(S_{bs})_{Qi} = Ph^2\frac{c_i}{12I_1E_b}\frac{1 + 2\alpha^2K}{1 + 2K}$

$(S_{bs})_{Qo} = Ph^2 \dfrac{c_o}{12 I_1 E_b} \dfrac{1+2\alpha^2 K}{1+2K}$		
$(S_T)_{Ni} = S_{ms} + (S_b)_{Ni}$		
$(S_T)_{No} = S_{ms} + (S_b)_{No}$		
$(S_{Ts})_{Qi} = S_{ms} + (S_{bs})_{Qi}$		
$(S_{Ts})_{Qo} = S_{ms} + (S_{bs})_{Qo}$		
Plate Parameters		
New / Corroded		
$c_i = \dfrac{15.88 - 0 - 0}{2} =$	7.94 mm	
$c_o = -\dfrac{15.88 - 0 - 0}{2} =$	-7.94 mm	
Operating Hot & Corroded		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ms} = 6.89 \cdot 1.02 \cdot \dfrac{165.1}{4 \cdot 15.88 \cdot 1} \cdot \left\{4 - \left[\dfrac{2 + 3.7809 \cdot (5 - 0.9231^2)}{1 + 2 \cdot 3.7809}\right]\right\} =$	35.365	1,315.434
$(S_b)_{Ni} = 6.89 \cdot 1.02 \cdot \dfrac{7.94}{24 \cdot 333.3957 \cdot 1} \cdot \left[-3 \cdot 152.4^2 + 2 \cdot 165.1^2 \cdot \dfrac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809}\right] =$	-155.418	1,973.151
$(S_b)_{No} = 6.89 \cdot 1.02 \cdot -\dfrac{7.94}{24 \cdot 333.3957 \cdot 1} \cdot \left[-3 \cdot 152.4^2 + 2 \cdot 165.1^2 \cdot \dfrac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809}\right] =$	155.418	1,973.151
$(S_{bs})_{Qi} = 6.89 \cdot 1.02 \cdot 165.1^2 \cdot \dfrac{7.94}{12 \cdot 333.3957 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	330.544	1,973.151
$(S_{bs})_{Qo} = 6.89 \cdot 1.02 \cdot 165.1^2 \cdot -\dfrac{7.94}{12 \cdot 333.3957 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	-330.544	1,973.151
$(S_T)_{Ni} = 35.365 + -155.418 =$	-120.052	1,973.151
$(S_T)_{No} = 35.365 + 155.418 =$	190.783	1,973.151
$(S_{Ts})_{Qi} = 35.365 + 330.544 =$	365.909	1,973.151
$(S_{Ts})_{Qo} = 35.365 + -330.544 =$	-295.178	1,973.151
Shop Test New		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{ms} = 30.17 \cdot 1.02 \cdot \dfrac{165.1}{4 \cdot 15.88 \cdot 1} \cdot \left\{4 - \left[\dfrac{2 + 3.7809 \cdot (5 - 0.9231^2)}{1 + 2 \cdot 3.7809}\right]\right\} =$	154.768	2,404.491
$(S_b)_{Ni} = 30.17 \cdot 1.02 \cdot \dfrac{7.94}{24 \cdot 333.3957 \cdot 1} \cdot \left[-3 \cdot 152.4^2 + 2 \cdot 165.1^2 \cdot \dfrac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809}\right] =$	-680.147	3,606.736
$(S_b)_{No} = 30.17 \cdot 1.02 \cdot -\dfrac{7.94}{24 \cdot 333.3957 \cdot 1} \cdot \left[-3 \cdot 152.4^2 + 2 \cdot 165.1^2 \cdot \dfrac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809}\right] =$	680.147	3,606.736
$(S_{bs})_{Qi} = 30.17 \cdot 1.02 \cdot 165.1^2 \cdot \dfrac{7.94}{12 \cdot 333.3957 \cdot 1} \cdot \dfrac{1 + 2 \cdot 0.9231^2 \cdot 3.7809}{1 + 2 \cdot 3.7809} =$	1,446.54	3,606.736

$(S_{bs})_{Qo} = 30.17 \cdot 1.02 \cdot 165.1^{\ 2} \cdot -\dfrac{7.94}{12 \cdot 333.3957 \cdot 1} \cdot \dfrac{1+2 \cdot 0.9231^{\ 2} \cdot 3.7809}{1+2 \cdot 3.7809} =$	-1,446.54	3,606.736
$(S_T)_{Ni} = 154.768 + -680.147 =$	-525.379	3,606.736
$(S_T)_{No} = 154.768 + 680.147 =$	834.915	3,606.736
$(S_{Ts})_{Qi} = 154.768 + 1{,}446.54 =$	1,601.308	3,606.736
$(S_{Ts})_{Qo} = 154.768 + -1{,}446.54 =$	-1,291.772	3,606.736

Stay		
$S_{mst} = P\dfrac{h}{2t_3E_{st}}\left[\dfrac{2+K\left(5-\alpha^2\right)}{1+2K}\right]$		
Operating Hot & Corroded		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{mst} = 6.89 \cdot 1.02 \cdot \dfrac{165.1}{2 \cdot 12 \cdot 1} \cdot \left[\dfrac{2+3.7809 \cdot \left(5-0.9231^{\ 2}\right)}{1+2 \cdot 3.7809}\right] =$	99.89	1,315.434
Shop Test New		
	Stress (kg_f/cm^2)	**Allow (kg_f/cm^2)**
$S_{mst} = 30.17 \cdot 1.02 \cdot \dfrac{165.1}{2 \cdot 12 \cdot 1} \cdot \left[\dfrac{2+3.7809 \cdot \left(5-0.9231^{\ 2}\right)}{1+2 \cdot 3.7809}\right] =$	437.144	2,404.491

End Plates for Return Header

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Appendix 13 End Plate		
Material		SA-516 70 (II-D Metric p. 20, ln. 45)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	
No	No	No	Yes	
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		6.89	343.33	-28.89
External		1.03	343.33	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Test horizontal		0.03	342.9	1
Dimensions				
Short Inside Length (d)		152.4 mm		
Long Inside Length (D)		165.1 mm		
Nominal Thickness		12 mm		
Corrosion	**Inner**	0 mm		
	Outer	0 mm		
Joint Efficiency		1		

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	1.5 mm + 0 mm = 1.5 mm
Design thickness due to internal pressure (t)	5.42 mm
Design thickness due to external pressure (t_e)	2.1 mm
Maximum allowable working pressure (MAWP)	33.76 bar
Maximum allowable pressure (MAP)	36.11 bar
Maximum allowable external pressure (MAEP)	33.76 bar
Rated MDMT	-48°C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	12 mm
Exemption temperature from Fig UCS-66M Curve B =	-23.31°C
$\text{Stress ratio per UCS-66}(b)(1)(b) = \frac{22.26}{36.11} =$	0.6163
Reduction in MDMT, T_R from Fig UCS-66.1M =	21.5°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
$MDMT = \max\left[MDMT - T_R - T_{PWHT}, -48\right] = \max\left[-23.31 - 21.5 - 17, -48\right] =$	-48°C
Material is exempt from impact testing at the Design MDMT of -28.89°C.	

Factor C from Appendix 13-4(f)

$\text{Factor} \quad C = 0.2$

Factor Z

$$Z = \min\left[3.4 - \frac{2.4 \cdot d}{D}, 2.5\right] = \min\left[3.4 - \frac{2.4 \cdot d}{165.1}, 2.5\right] = 1.1846$$

Design thickness, (at 343.33 °C) UG-34(c)(3)

$$t = d \cdot \sqrt{\frac{Z \cdot C \cdot P \cdot 1.02}{S \cdot E}} + \text{Corrosion} = 152.4 \cdot \sqrt{\frac{1.1846 \cdot 0.2 \cdot 6.89 \cdot 1.02}{1{,}315.434 \cdot 1}} + 0 = \underline{5.42} \quad \text{mm}$$

Maximum allowable working pressure, (at 343.33 °C)

$$MAWP = \left(\frac{S \cdot E}{C \cdot Z}\right) \cdot \left(\frac{t}{d}\right)^2 - P_s = \left(\frac{\frac{1{,}315.434}{1.02} \cdot 1}{0.2 \cdot 1.1846}\right) \cdot \left(\frac{12}{152.4}\right)^2 - 0 = \underline{33.76} \quad \text{bar}$$

Maximum allowable pressure, (At 21.11 °C)

$$Z = \min\left[3.4 - \frac{2.4 \cdot d}{D}, 2.5\right] = \min\left[3.4 - \frac{2.4 \cdot d}{165.1}, 2.5\right] = 1.1846$$

$$MAP = \left(\frac{S \cdot E}{C \cdot Z}\right) \cdot \left(\frac{t}{d}\right)^2 = \left(\frac{\frac{1{,}407.208}{1.02} \cdot 1}{0.2 \cdot 1.1846}\right) \cdot \left(\frac{12}{152.4}\right)^2 = \underline{36.11} \quad \text{bar}$$

Design thickness for external pressure, (at 343.33 °C) UG-34(c)(3)

$$t = d \cdot \sqrt{\frac{Z \cdot C \cdot P_e \cdot 1.02}{S \cdot E}} + \text{Corrosion} = 152.4 \cdot \sqrt{\frac{1.1846 \cdot 0.2 \cdot 1.03 \cdot 1.02}{1{,}315.434 \cdot 1}} + 0 = \underline{2.1} \quad \text{mm}$$

Maximum allowable external pressure, (At 343.33 °C)

$$\text{MAEP} = \left(\frac{S \cdot E}{C \cdot Z}\right) \cdot \left(\frac{t}{d}\right)^2 = \left(\frac{\frac{1{,}315.434}{1.02} \cdot 1}{0.2 \cdot 1.1846}\right) \cdot \left(\frac{12}{152.4}\right)^2 = \underline{33.76} \quad \text{bar}$$