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DESIGN CALCULATION

In Accordance with ASME Section VIII Division 1

ASME Code Version : 2023

Analysis Performed by : Kedkep Consulting Inc

Job File : D:\Jobs 2008 to today\Business\web\UHX.pvdb

Date of Analysis : Jun 10,2025 9:53pm

PV Elite 27, January 2025

Vessel Design Summary:

ASME Code, Section VIII Division 1, 2023

Diameter Spec : 32.000 in. ID		
Vessel Design Length, Tangent to Tangent	10.71	ft.
Specified Datum Line Distance	0.00	ft.
Shell Side Design Temperature	212	F
Channel Side Design Temperature	295	F
Shell Side Design Pressure	100.000	psig
Channel Side Design Pressure	300.000	psig
Shop Shell Side Test Pressure	130.000	psig
Shop Channel Side Test Pressure	130.000	psig
Wind Design Code	ASCE-93	
Earthquake Design Code	UBC-94	

Materials of Construction:

Component Type	Material	Class	Thickness	UNS #	Normalized	Impact Tested
Shell	SA-240 304	...	...	S30400	No	No
Shell	SA-516 70	...	...	K02700	No	No
Head	SA-240 304	...	...	S30400	No	No
Head	SA-516 70	...	...	K02700	No	No
Flange	SA-516 70	...	...	K02700	No	No
Tubes	SA-214	...	...	K01807	No	No
Tubesheet	SA-516 70	...	...	K02700	No	No
Flg Bolting	SA-193 B7	...	<= 2 1/2	G41400	No	No

'Normalized is determined based on the UCS-66 material curve selection and Figure UCS-66.
'Impact Tested is based on material selection and material data properties.

Element Pressures and MAWP (psig & in.):

Element Description or Type	Design Pressure + Stat. head	Ext. Press.	Element M.A.W.P	Total Corrosion Allowance	Str. Flg. Gov.	In Creep Range
Lft Head	300.000	15.00	403.400	0.0625	No	No
Channel	300.000	15.00	672.300	0.0625	N/A	No
Flange 1	300.000	15.00	359.800	0.0625	N/A	No
Shell	100.000	15.00	455.600	0.0625	N/A	No
Flange 2	300.000	15.00	359.800	0.0625	N/A	No
RT Channel	300.000	15.00	672.300	0.0625	N/A	No
RT Head	100.000	15.00	424.900	0.0625	No	No

Element Types and Properties:

Element Type	"To" Elev ft.	Element Length ft.	Nominal Thickness in.	Finished Thickness in.	Reqd Thk Internal in.	Reqd Thk External in.	Long Eff	Circ Eff
Torisph	0.17	0.167	0.750	0.688	0.527	0.165	1.00	0.85

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Cylinder	1.17	1.000	0.750	0.750	0.365	0.144	0.85	0.85
Body Flg	1.52	0.333	...	4.000	3.893	3.293	0.85	0.85
Cylinder	9.35	8.000	0.500	0.500	0.157	0.226	0.85	0.85
Body Flg	9.54	0.333	...	4.000	3.893	3.293	0.85	0.85
Cylinder	10.54	1.000	0.750	0.750	0.365	0.144	0.85	0.85
Torisph	10.71	0.167	0.750	0.688	0.209	0.160	1.00	0.85

Weights:

Fabricated	- Bare w/o removable internals	5557.6	lbm
Shop Test	- Fabricated + water (full)	9162.8	lbm
Shipping	- Fab. + rem. intls.+ shipping app.	5557.6	lbm
Erected	- Fab. + rem. intls.+ insul. (etc)	5557.6	lbm
Empty	- Fab. + intls. + details + wghts.	5557.6	lbm
Operating	- Empty + operating liquid (no ca)	5557.6	lbm

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Bill of Materials:

QTY	DESCRIPTION	MATERIAL
1	TORISPHERICAL HEAD: 0.750" THK X 32.000" ID X 2.00"	SA-240 304
2	CYLINDER: 0.750" THK X 32.000" ID X 1'	SA-240 304
2	SLIP ON FLANGE: 4.000" THK X 38.400" OD	SA-516 70
1	CYLINDER: 0.500" THK X 32.000" ID X 8'	SA-516 70
1	TORISPHERICAL HEAD: 0.750" THK X 32.000" ID X 2.00"	SA-516 70
2	TUBESHEET: 38.400" X 2.000" THK	SA-516 70
348	TUBES: 90.000" X 0.750" DIA X 0.062" THK	SA-214
2	GASKET: 32.750" OD X 32.000" ID	...
56	BODY FLANGE BOLTS: 1.000" DIA	SA-193 B7
56	NUTS FOR BODY FLANGE BOLTS: 1.000" DIA	...
1	NAMEPLATE	...

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Minimum Design Metal Temperature Results Summary (F):

Description	Notes	Curve	Basic MDMT	Reduced MDMT	UG-20(f) MDMT	Thickness ratio	Gov Thk in.	E*	PWHT reqd
Shell	[8]	B	-6	-155	-20	0.184	0.500	0.85	No
Tubesheet: SS	[13]	B	-6	-41	-20	0.655	0.500	1.00	No
Warmest MDMT:			-6	-41					
Lft Head	[16]		-320						
Channel	[16]		-320						
RT Channel	[16]		-320						
RT Head	[10]	B	11	-155	-20	0.235	0.688	1.00	No
RT Head	[7]	B	16	-155	-20	0.136	0.750	1.00	No
Tubesheet: CS	[14]	B	-6	-41	-20	0.655	0.500	1.00	No
Warmest MDMT:			16	-41					

Exchanger Side	Computed MDMT	Required MDMT	Pass/Fail
Shell	-41.0	-20.0	Pass
Channel/Tube	-41.0	-20.0	Pass

Notes:
[!] - This was an impact tested material.
[1] - Governing Nozzle Weld.
[4] - ASME Flange MDMT Calcs; Thickness ratio per UCS-66(b)(1)(-c).
[5] - ASME Flange MDMT Calcs; Thickness ratio per UCS-66(b)(1)(-b).
[6] - MDMT Calculations at the Shell/Head Joint.
[7] - MDMT Calculations for the Straight Flange.
[8] - Cylinder/Cone/Flange Junction MDMT.
[9] - Calculations in the Spherical Portion of the Head.
[10] - Calculations in the Knuckle Portion of the Head.
[11] - Calculated (Body Flange) Flange MDMT.
[12] - Calculated Flat Head MDMT per UCS-66.3
[13] - Tubesheet MDMT, shell side, if applicable
[14] - Tubesheet MDMT, tube side, if applicable
[15] - Nozzle Material
[16] - Shell or Head Material
[17] - Impact Testing required
[18] - Impact Testing not required, see UCS-66(b)(3)
[20] - Cylinder/Cone Junction MDMT based on Longitudinal Stress considerations
[21] - Body Flange Bolting Material
[22] - Nozzle Flange Bolting Material
[23] - Stiffening Ring to Shell Weld
[24] - Saddle to Shell Weld

UG-84(b)(2) was not considered.
UCS-66(g) was not considered.
UCS-66(i) was not considered.

Notes:
Impact test temps were not entered in and not considered in the analysis.
UCS-66(i) applies to impact tested materials not by specification and
UCS-66(g) applies to materials impact tested per UG-84.1 General Note (c).
The Basic MDMT includes the (30F) PWHT credit if applicable.

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Class From To : Basic Element Checks.

Class From To: Check of Additional Element Data

There were no geometry errors or warnings.

The ASME Code Section VIII Division 1 does not explicitly require stresses on elements to be computed under test conditions. Please see interpretation VIII-1-10-12 for more information.
PV Elite also computes weight due to test fluid and uses the weight in various calculations such as saddle and leg loads. PV Elite also computes static pressure due to operating and test liquids. The static pressure is used in conjunction with the design and test pressures to determine a total pressure in the determination of required thickness, MAWP etc. This ensures compliance with UG-22 requirements.

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Units used in this Analysis (ENGLISH):

Name	System Unit	Constant	User Unit
Length	Feet	1.0000	ft.
Force	Pounds	1.0000	lb.
Mass	Pounds	1.0000	lbm
Area	sq. inches	1.0000	sq.in.
Moment	ft. lbs.	1.0000	ft.lb.
Stress	lbs./sq.in.	1.0000	psi
Temperature	Degrees F	1.0000	F
Pressure	psig	1.0000	psig
Elast. Modulus	lbs./sq.in.	1.0000	psi
Pipe Density	lbs./cu.in.	1.0000	lb./cu.in.
Ins. Density	lbs./cu.ft.	1.0000	lb./cu.ft.
Fluid Density	lbs./cu.ft.	1.0000	lb./cu.ft.
Wind Speed	miles/hr	1.0000	mile/hr
Tray Weight	lbs./sq.ft.	1.0000	lb./sq.ft.
Inertia	in.^4	1.0000	in**4
G Load	G's	1.0000	g's
Wind Load	lbs./sq.ft.	1.0000	psf
Elevation	Feet	1.0000	ft.
Volume	in.^3	1.0000	in3
Diameter	inches	1.0000	in.
Thickness	inches	1.0000	in.

PV Elite Vessel Analysis Program: Input Data

Exchanger Design Pressures and Temperatures

Shell Side Design Pressure	100	psig
Channel Side Design Pressure	300	psig
Shell Side Design Temperature	212.0	F
Channel Side Design Temperature	295.0	F
Radiography, Shell Side	RT-1	
Radiography, Channel Side	RT-1	
Service Type, Shell Side	Air/Water/Steam	
Service Type, Channel Side	Air/Water/Steam	
MDMT (CET), Shell Side	-20.0	F
MDMT (CET), Tube Side	-20.0	F
User defined MAWP, Shell Side	0	psig
User defined MAWP, Channel Side	0	psig
User defined MAPnc, Shell Side	0	psig
User defined MAPnc, Channel Side	0	psig
User defined Test Pres., Shell Side	0	psig
User defined Test Pres., Channel Side	0	psig

Projection of Nozzle from Vessel Top	0	in.
Projection of Nozzle from Vessel Bottom	0	in.
Type of Construction	Welded	
Use Higher Longitudinal Stresses (Flag)	Y	
Select t for Internal Pressure (Flag)	N	
Select t for External Pressure (Flag)	N	
Select t for Axial Stress (Flag)	N	
Select Location for Stiff. Rings (Flag)	N	
Consider Vortex Shedding	N	

Shop Pressure Test:

Type of Pressure Test	UG-99(b) Note [35]	
Pressure Test Position	Horizontal	
Test Performed in Corroded Condition	No	
Load Case 1	NP+EW+WI+FW+BW	
Load Case 2	NP+EW+EE+FS+BS	
Load Case 3	NP+OW+WI+FW+BW	
Load Case 4	NP+OW+EQ+FS+BS	
Load Case 5	NP+HW+HI	
Load Case 6	NP+HW+HE	
Load Case 7	IP+OW+WI+FW+BW	
Load Case 8	IP+OW+EQ+FS+BS	
Load Case 9	EP+OW+WI+FW+BW	
Load Case 10	EP+OW+EQ+FS+BS	
Load Case 11	HP+HW+HI	
Load Case 12	HP+HW+HE	
Load Case 13	IP+WE+EW	
Load Case 14	IP+WF+CW	
Load Case 15	IP+VO+OW	
Load Case 16	IP+VE+EW	
Load Case 17	NP+VO+OW	
Load Case 18	FS+BS+IP+OW	
Load Case 19	FS+BS+EP+OW	
Wind Design Code	ASCE-7 93	
Basic Wind Speed [V]	70	mile/hr
Surface Roughness Category	C: Open Terrain	
Importance Factor	1.0	
Type of Surface	Moderately Smooth	
Base Elevation	0	ft.
Percent Wind for Hydrotest	33.0	
Using User defined Wind Press. Vs Elev.	N	
Damping Factor (Beta) for Wind (Ope)	0.0100	
Damping Factor (Beta) for Wind (Empty)	0.0000	
Damping Factor (Beta) for Wind (Filled)	0.0000	
Seismic Design Code	UBC 94	
UBC Seismic Zone (1=1,2=2a,3=2b,4=3,5=4)	4.000	
UBC Importance Factor	1.000	
UBC Soil Type	S3	
UBC Horizontal Force Factor	3.000	
UBC Percent Seismic for Hydrotest	0.000	
Design Pressure + Static Head	Y	
Consider MAP New and Cold in Noz. Design	N	
Consider External Loads for Nozzle Des.	Y	
Use ASME VIII-1 Appendix 1-9	N	
Perform Blast Load Analysis	No	
Material Database Year	Current w/Addenda or Code Year	

Configuration Directives:

g0 is taken as min(g0, attached shell thk)	Yes
Do not use Nozzle MDMT Interpretation VIII-1 01-37	No
Use Table G instead of exact equation for "A"	No
Shell Head Joints are Tapered	No
Compute "K" in corroded condition	No
Use Code Case 2286	No
Use the MAWP to compute the MDMT	No

For thickness ratios <= 0.35, MDMT will be -155F (-104C)	Yes
For PWHT & P1 Materials the MDMT can be < -55F (-48C)	No
Using Metric Material Databases, ASME II D	No
Calculate B31.3 type stress for Nozzles with Loads	Yes
Reduce the MDMT due to lower membrane stress	Yes
Consider Longitudinal Stress in MDMT Calculations	Yes

Complete Listing of Vessel Elements and Details:

Element#	1/7	
Element From Node	10	
Element To Node	20	
Element Type	Torispherical	
Description	Lft Head	
Distance "FROM" to "TO"	0.1667	ft.
Inside Diameter	32	in.
Element Thickness	0.6875	in.
Internal Corrosion Allowance	0.0625	in.
Nominal Thickness	0.75	in.
External Corrosion Allowance	0	in.
Design Internal Pressure	300	psig
Design Temperature Internal Pressure	295	F
Design External Pressure	15	psig
Design Temperature External Pressure	295	F
Effective Diameter Multiplier	1.2	
Material Name	SA-240 304	
Allowable Stress, Ambient	20000	psi
Allowable Stress, Operating	18955	psi
Allowable Stress, Hydrotest	27000	psi
Material Density	0.29	lb./cu.in.
P Number Thickness	0	in.
Yield Stress, Operating	22520	psi
External Pressure Chart Name	HA-1	
UNS Number	S30400	
Product Form	Plate	
Efficiency, Longitudinal Seam	1.0	
Efficiency, Circumferential Seam	0.85	
Tori Head Crown Radius	33.312	in.
Tori Head Knuckle Radius	1.9987	in.
Weld is pre-Heated	No	

Element#	2/7	
Element From Node	20	
Element To Node	30	
Element Type	Cylinder	
Description	Channel	
Distance "FROM" to "TO"	1	ft.
Inside Diameter	32	in.
Element Thickness	0.75	in.
Internal Corrosion Allowance	0.0625	in.
Nominal Thickness	0.75	in.
External Corrosion Allowance	0	in.
Design Internal Pressure	300	psig
Design Temperature Internal Pressure	295	F
Design External Pressure	15	psig
Design Temperature External Pressure	295	F
Effective Diameter Multiplier	1.2	
Material Name	SA-240 304	
Efficiency, Longitudinal Seam	0.85	

Efficiency, Circumferential Seam	0.85	
Weld is pre-Heated	No	

Element#	3/7	
Element From Node	30	
Element To Node	40	
Element Type	Flange	
Description	Flange 1	
Distance "FROM" to "TO"	0.3333	ft.
Flange Inside Diameter	32	in.
Element Thickness	4	in.
Internal Corrosion Allowance	0.0625	in.
Nominal Thickness	0	in.
External Corrosion Allowance	0	in.
Design Internal Pressure	300	psig
Design Temperature Internal Pressure	295	F
Design External Pressure	15	psig
Design Temperature External Pressure	295	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Allowable Stress, Ambient	20000	psi
Allowable Stress, Operating	20000	psi
Allowable Stress, Hydrotest	34200	psi
Material Density	0.28	lb./cu.in.
P Number Thickness	1.25	in.
Yield Stress, Operating	33660	psi
UCS-66 Chart Curve Designation	B	
External Pressure Chart Name	CS-2	
UNS Number	K02700	
Product Form	Plate	
Perform Flange Stress Calculation (Y/N)	Y	
Weld is pre-Heated	No	

Element#	4/7	
Element From Node	40	
Element To Node	50	
Element Type	Cylinder	
Description	Shell	
Distance "FROM" to "TO"	8	ft.
Inside Diameter	32	in.
Element Thickness	0.5	in.
Internal Corrosion Allowance	0.0625	in.
Nominal Thickness	0.5	in.
External Corrosion Allowance	0	in.
Design Internal Pressure	100	psig
Design Temperature Internal Pressure	212	F
Design External Pressure	15	psig
Design Temperature External Pressure	212	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Efficiency, Longitudinal Seam	0.85	
Efficiency, Circumferential Seam	0.85	
Weld is pre-Heated	No	

Element#	5/7	
Element From Node	50	

Element To Node	60	
Element Type	Flange	
Description	Flange 2	
Distance "FROM" to "TO"	0.3333	ft.
Flange Inside Diameter	32	in.
Element Thickness	4	in.
Internal Corrosion Allowance	0.0625	in.
Nominal Thickness	0	in.
External Corrosion Allowance	0	in.
Design Internal Pressure	300	psig
Design Temperature Internal Pressure	295	F
Design External Pressure	15	psig
Design Temperature External Pressure	295	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Perform Flange Stress Calculation (Y/N)	Y	
Weld is pre-Heated	No	

Element#	6/7	
Element From Node	60	
Element To Node	70	
Element Type	Cylinder	
Description	RT Channel	
Distance "FROM" to "TO"	1	ft.
Inside Diameter	32	in.
Element Thickness	0.75	in.
Internal Corrosion Allowance	0.0625	in.
Nominal Thickness	0.75	in.
External Corrosion Allowance	0	in.
Design Internal Pressure	300	psig
Design Temperature Internal Pressure	295	F
Design External Pressure	15	psig
Design Temperature External Pressure	295	F
Effective Diameter Multiplier	1.2	
Material Name	SA-240 304	
Allowable Stress, Ambient	20000	psi
Allowable Stress, Operating	18955	psi
Allowable Stress, Hydrotest	27000	psi
Material Density	0.29	lb./cu.in.
P Number Thickness	0	in.
Yield Stress, Operating	22520	psi
External Pressure Chart Name	HA-1	
UNS Number	S30400	
Product Form	Plate	
Efficiency, Longitudinal Seam	0.85	
Efficiency, Circumferential Seam	0.85	
Weld is pre-Heated	No	

Element#	7/7	
Element From Node	70	
Element To Node	80	
Element Type	Torispherical	
Description	RT Head	
Distance "FROM" to "TO"	0.1667	ft.
Inside Diameter	32	in.
Element Thickness	0.6875	in.
Internal Corrosion Allowance	0.0625	in.
Nominal Thickness	0.75	in.

External Corrosion Allowance	0	in.
Design Internal Pressure	100	psig
Design Temperature Internal Pressure	295	F
Design External Pressure	15	psig
Design Temperature External Pressure	295	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Allowable Stress, Ambient	20000	psi
Allowable Stress, Operating	20000	psi
Allowable Stress, Hydrotest	34200	psi
Material Density	0.28	lb./cu.in.
P Number Thickness	1.25	in.
Yield Stress, Operating	33660	psi
UCS-66 Chart Curve Designation	B	
External Pressure Chart Name	CS-2	
UNS Number	K02700	
Product Form	Plate	
Efficiency, Longitudinal Seam	1.0	
Efficiency, Circumferential Seam	0.85	
Tori Head Crown Radius	33.375	in.
Tori Head Knuckle Radius	2.0025	in.
Weld is pre-Heated	No	

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XY Coordinate Calculations:

From	To	X (Horiz.) ft.	Y (Vert.) ft.	DX (Horiz.) ft.	DY (Vert.) ft.
Lft Head		0.16667	...	0.16667	...
Channel		1.16667	...	1	...
Flange 1		1.52083	...	0.33333	...
Shell		9.35417	...	8	...
Flange 2		9.54167	...	-0.33333	...
RT Channel		10.5417	...	1	...
RT Head		10.7083	...	0.16667	...

PV Elite includes an 1/8 inch (3.175mm) raised face and gasket thicknesses for girth flanges and tubesheet thicknesses where applicable in the Tangent to Tangent length calculation. The calculated dimensions are based on the given element lengths. Due to variability in manufacturing (weld gaps etc.), the Tangent to Tangent length may not be exact.

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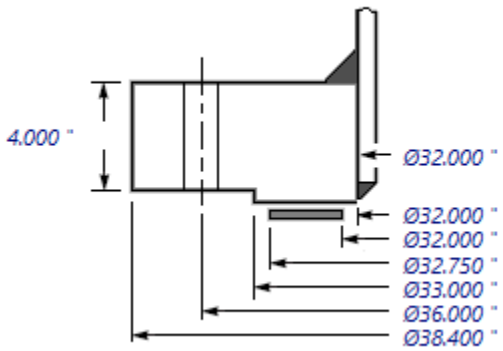
Flange Input Data Values **Description:** Flange 1 :

Flange 1

Flange Type/Sketch		Loose Ring	
Design Pressure	P	300.00	psig
Design Temperature		295	F
Internal Corrosion Allowance	ci	0.0625	in.
External Corrosion Allowance	ce	0.0000	in.
Use Corrosion Allowance in Thickness Calcs.		No	
Flange Inside Diameter	B	32.000	in.
Flange Outside Diameter	A	38.400	in.
Flange Thickness	t	4.0000	in.
Flange Material		SA-516 70	
Flange Material UNS number		K02700	
Flange Allowable Stress At Temperature	Sfo	20000.00	psi
Flange Allowable Stress At Ambient	Sfa	20000.00	psi
Bolt Material		SA-193 B7	
Bolt Allowable Stress At Temperature	Sb	25000.00	psi
Bolt Allowable Stress At Ambient	Sa	25000.00	psi
Length of Weld Leg at Back of Ring	tw	0.0000	in.
Number of Splits in Ring Flange	n	0	
Diameter of Bolt Circle	C	36.000	in.
Nominal Bolt Diameter	a	1.0000	in.
Type of Threads		TEMA Thread Series	
Number of Bolts		28	
Flange Face Outside Diameter	Fod	33.000	in.
Flange Face Inside Diameter	Fid	32.000	in.
Flange Facing Sketch		1, Code Sketch 1a	
Gasket Outside Diameter	Go	32.750	in.
Gasket Inside Diameter	Gi	32.000	in.
Gasket Factor	m	0.5000	
Gasket Design Seating Stress	y	0.00	psi
Column for Gasket Seating		2, Code Column II	
Gasket Thickness	tg	0.1250	in.



ASME Code, Section VIII Division 1, 2023

Code R Dimension,	R = (C-B)/2 - g1	2.000 in.
Gasket Contact Width,	N = (Go - Gi)/2	0.375 in.
Basic Gasket Width,	bo = N/2	0.188 in.
Effective Gasket Width,	b = bo	0.188 in.
Gasket Reaction Diameter,	G = (Go + Gi)/2	32.375 in.

Basic Flange and Bolt Loads:

Hydrostatic End Load due to Pressure [H]:
= pi/4 * G^2 * Peq
= pi/4 * 32.38^2 * 300
= 246962.328 lb.

Contact Load on Gasket Surfaces [Hp]:
= 2 * b * pi * G * m * P
= 2 * 0.188 * pi * 32.38 * 0.5 * 300
= 5721.135 lb.

Hydrostatic End Load at Flange ID [Hd]:
= pi/4 * Bcor^2 * P
= pi/4 * 32^2 * 300
= 241274.328 lb.

Pressure Force on Flange Face [Ht]:
= H - Hd
= 246962 - 241274
= 5688.000 lb.

Operating Bolt Load [Wm1]:
= max(H + Hp + H'p, 0)
= max(246962 + 5721 + 0, 0)
= 252683.469 lb.

Gasket Seating Bolt Load [Wm2]:
= y * b * pi * G + yPart * bPart * lp
= 0*0.188*pi*32.38+0*0*0
= 0.000 lb.

Required Bolt Area [Am]:
= max(Wm1/Sb, Wm2/Sa)
= max(252683/25000, 0/25000)
= 10.107 sq.in.

ASME Maximum Circumferential Spacing between Bolts per App. 2 eq. (3) [Bsmax]:
= 2a + 6t/(m + 0.5)
= 2 * 1 + 6 * 4/(0.5 + 0.5)
= 26.000 in.

Actual Circumferential Bolt Spacing [Bs]:
= C * sin(pi / n)
= 36 * sin(pi/28)
= 4.031 in.

ASME Moment Multiplier for Bolt Spacing per App. 2 eq. (7) [Bsc]:
= max(sqrt(Bs/(2a + t)), 1)
= max(sqrt(4.031/(2 * 1 + 4)), 1)
= 1.0000

Bolting Information for TEMA Imperial Thread Series (Non Mandatory):

	Minimum	Actual	Maximum
Bolt Area:	10.107	15.428	
Radial Distance between Hub and Bolts:	1.062	2.000	
Radial Distance between Bolts and Edge:	1.062	1.200	
Circ. Spacing between the Bolts:	2.250	4.031	26.000

Flange Design Bolt Load, Gasket Seating [W]:
= Sa(Am + Ab) / 2
= 25000 (10.11 + 15.43)/2
= 319191.75 lb.

Gasket Load for the Operating Condition [HG]:
= Wm1 - H
= 252683 - 246962
= 5721.14 lb.

Moment Arm Calculations:

Distance to Gasket Load Reaction [hg]:
= (C - G) / 2
= (36 - 32.38)/2
= 1.8125 in.

Distance to Face Pressure Reaction [ht]:
= (hD + hG) / 2
= (2 + 1.812)/2
= 1.9062 in.

Distance to End Pressure Reaction [hd]:
= (C - Bcor)/ 2
= (36 - 32)/2
= 2.0000 in.

Summary of Moments for Internal Pressure: (ft.lb.)

Loading		Force	Distance	Bolt Corr	Moment
End Pressure,	Md	241274.	2.0000	1.0000	40212.
Face Pressure,	Mt	5688.	1.9062	1.0000	904.
Gasket Load,	Mg	5721.	1.8125	1.0000	864.
Gasket Seating,	Matm	319192.	1.8125	1.0000	48211.

Total Moment for Operation, Mop 41980. ft.lb.
Total Moment for Gasket seating, Matm 48211. ft.lb.

Effective Hub Length, ho = 0.000 in.
Hub Ratio, h/h0 = Defined as 0 0.000
Thickness Ratio, g1/g0 = Defined as 0.0 0.000

Factors from Figure 2-7.1 K = 1.200
T = 1.839 U = 11.813
Y = 10.750 Z = 5.545

Tangential Flange Stress, Operating [Sto]:
= (Y * Mop)/(t² * Bcor)
= (10.75*503761)/(4²*32)
= 10576.62 psi

Tangential Flange Stress, Seating [STa]:
= (Y * Matm)/(t² * Bcor)

= (10.75*578535)/(4²*32)
= 12146.52 psi

Bolt Stress, Operating [BSo]:
= Wm1 / Ab
= 252683/15.43
= 16378.24 psi

Bolt Stress, Seating [BSa]:
= (Wm2 / Ab)
= (0/15.43)
= 0.00 psi

Flange Stress Analysis Results: psi

	Operating		Gasket Seating	
	Actual	Allowed	Actual	Allowed
Tangential Flange	10576.62	20000.00	12146.52	20000.00
Bolting	16378.24	25000.00	0.00	25000.00

Minimum Required Flange Thickness [Rigidity]	3.893 in.
Estimated M.A.W.P. (Operating)	359.8 psig
Estimated Finished Weight of Flange at given Thk.	396.3 lbm
Estimated Unfinished Weight of Forging at given Thk	396.3 lbm

Flange Rigidity Based on Required Thickness [ASME]:

Flange Rigidity Index, Seating (rotation check) per APP. 2 [Js]:
= 109.4 * Ma / Bsc * Cnv_fac / (Eamb * t^3 * ln(K) * Kl)
= 109.4 * 48211/1 * 12/(29400000 * 3.893^3 * 0.182 * 0.2)
= 1.000 (should be <= 1)

Flange Rigidity Index Operating (rotation check) per APP. 2 [J]:
= 109.4 * Mo / Bsc * Cnv_fac / (Eop * tc^3 * ln(K) * Kl)
= 109.4 * 41980/1 * 12/(28324998 * 3.893^3 * 0.182 * 0.2)
= 0.904 (should be <= 1)

Flange Rigidity Based on Given Thickness [ASME]:

Flange Rigidity Index, Seating (rotation check) per APP. 2 [Js]:
= 109.4 * Ma / Bsc * Cnv_fac / (Eamb * t^3 * ln(K) * Kl)
= 109.4 * 48211/1 * 12/(29400000 * 4^3 * 0.182 * 0.2)
= 0.922 (should be <= 1)

Flange Rigidity Index Operating (rotation check) per APP. 2 [J]:
= 109.4 * Mo / Bsc * Cnv_fac / (Eop * tc^3 * ln(K) * Kl)
= 109.4 * 41980/1 * 12/(28324998 * 4^3 * 0.182 * 0.2)
= 0.833 (should be <= 1)

Required Fillet Weld Leg size for Slip on Flanges:

For Loose Slip on Flanges designed per 2-4 sketches (3-4c) [c]:
= min(tn, max(2 * tr, (1/4 inch or 6 mm)))
= min(0.438, max(2 * 0.349, (0.25)))
= 0.438 in.

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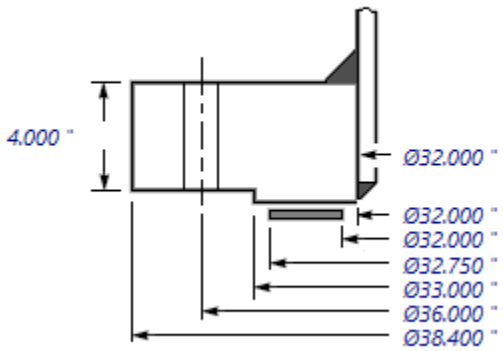
Flange Input Data Values **Description:** Flange 2 :

Flange 2

Flange Type/Sketch		Loose Ring	
Design Pressure	P	300.00	psig
Design Temperature		295	F
Internal Corrosion Allowance	ci	0.0625	in.
External Corrosion Allowance	ce	0.0000	in.
Use Corrosion Allowance in Thickness Calcs.		No	
Flange Inside Diameter	B	32.000	in.
Flange Outside Diameter	A	38.400	in.
Flange Thickness	t	4.0000	in.
Flange Material		SA-516 70	
Flange Material UNS number		K02700	
Flange Allowable Stress At Temperature	Sfo	20000.00	psi
Flange Allowable Stress At Ambient	Sfa	20000.00	psi
Bolt Material		SA-193 B7	
Bolt Allowable Stress At Temperature	Sb	25000.00	psi
Bolt Allowable Stress At Ambient	Sa	25000.00	psi
Length of Weld Leg at Back of Ring	tw	0.0000	in.
Number of Splits in Ring Flange	n	0	
Diameter of Bolt Circle	C	36.000	in.
Nominal Bolt Diameter	a	1.0000	in.
Type of Threads		TEMA Thread Series	
Number of Bolts		28	
Flange Face Outside Diameter	Fod	33.000	in.
Flange Face Inside Diameter	Fid	32.000	in.
Flange Facing Sketch		1, Code Sketch 1a	
Gasket Outside Diameter	Go	32.750	in.
Gasket Inside Diameter	Gi	32.000	in.
Gasket Factor	m	0.5000	
Gasket Design Seating Stress	y	0.00	psi
Column for Gasket Seating		2, Code Column II	
Gasket Thickness	tg	0.1250	in.



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Code R Dimension,	R = (C-B)/2 - g1	2.000 in.
Gasket Contact Width,	N = (Go - Gi)/2	0.375 in.
Basic Gasket Width,	bo = N/2	0.188 in.
Effective Gasket Width,	b = bo	0.188 in.
Gasket Reaction Diameter,	G = (Go + Gi)/2	32.375 in.

Basic Flange and Bolt Loads:

Hydrostatic End Load due to Pressure [H]:
= pi/4 * G^2 * Peq
= pi/4 * 32.38^2 * 300
= 246962.328 lb.

Contact Load on Gasket Surfaces [Hp]:
= 2 * b * pi * G * m * P
= 2 * 0.188 * pi * 32.38 * 0.5 * 300
= 5721.135 lb.

Hydrostatic End Load at Flange ID [Hd]:
= pi/4 * Bcor^2 * P
= pi/4 * 32^2 * 300
= 241274.328 lb.

Pressure Force on Flange Face [Ht]:
= H - Hd
= 246962 - 241274
= 5688.000 lb.

Operating Bolt Load [Wm1]:
= max(H + Hp + H'p, 0)
= max(246962 + 5721 + 0, 0)
= 252683.469 lb.

Gasket Seating Bolt Load [Wm2]:
= y * b * pi * G + yPart * bPart * lp
= 0*0.188*pi*32.38+0*0*0
= 0.000 lb.

Required Bolt Area [Am]:
= max(Wm1/Sb, Wm2/Sa)
= max(252683/25000, 0/25000)
= 10.107 sq.in.

ASME Maximum Circumferential Spacing between Bolts per App. 2 eq. (3) [Bsmax]:
= 2a + 6t/(m + 0.5)
= 2 * 1 + 6 * 4/(0.5 + 0.5)
= 26.000 in.

Actual Circumferential Bolt Spacing [Bs]:
= C * sin(pi / n)
= 36 * sin(pi/28)
= 4.031 in.

ASME Moment Multiplier for Bolt Spacing per App. 2 eq. (7) [Bsc]:
= max(sqrt(Bs/(2a + t)), 1)
= max(sqrt(4.031/(2 * 1 + 4)), 1)
= 1.0000

Bolting Information for TEMA Imperial Thread Series (Non Mandatory):

	Minimum	Actual	Maximum
Bolt Area:	10.107	15.428	
Radial Distance between Hub and Bolts:	1.062	2.000	
Radial Distance between Bolts and Edge:	1.062	1.200	
Circ. Spacing between the Bolts:	2.250	4.031	26.000

Flange Design Bolt Load, Gasket Seating [W]:
= Sa(Am + Ab) / 2
= 25000 (10.11 + 15.43)/2
= 319191.75 lb.

Gasket Load for the Operating Condition [HG]:
= Wm1 - H
= 252683 - 246962
= 5721.14 lb.

Moment Arm Calculations:

Distance to Gasket Load Reaction [hg]:
= (C - G) / 2
= (36 - 32.38)/2
= 1.8125 in.

Distance to Face Pressure Reaction [ht]:
= (hD + hG) / 2
= (2 + 1.812)/2
= 1.9062 in.

Distance to End Pressure Reaction [hd]:
= (C - Bcor)/ 2
= (36 - 32)/2
= 2.0000 in.

Summary of Moments for Internal Pressure: (ft.lb.)

Loading		Force	Distance	Bolt Corr	Moment
End Pressure,	Md	241274.	2.0000	1.0000	40212.
Face Pressure,	Mt	5688.	1.9062	1.0000	904.
Gasket Load,	Mg	5721.	1.8125	1.0000	864.
Gasket Seating,	Matm	319192.	1.8125	1.0000	48211.

Total Moment for Operation, Mop 41980. ft.lb.
Total Moment for Gasket seating, Matm 48211. ft.lb.

Effective Hub Length, ho = 0.000 in.
Hub Ratio, h/h0 = Defined as 0 0.000
Thickness Ratio, g1/g0 = Defined as 0.0 0.000

Factors from Figure 2-7.1 K = 1.200
T = 1.839 U = 11.813
Y = 10.750 Z = 5.545

Tangential Flange Stress, Operating [Sto]:
= (Y * Mop)/(t² * Bcor)
= (10.75*503761)/(4²*32)
= 10576.62 psi

Tangential Flange Stress, Seating [STa]:
= (Y * Matm)/(t² * Bcor)

= (10.75*578535)/(4²*32)
= 12146.52 psi

Bolt Stress, Operating [BSo]:
= Wm1 / Ab
= 252683/15.43
= 16378.24 psi

Bolt Stress, Seating [BSa]:
= (Wm2 / Ab)
= (0/15.43)
= 0.00 psi

Flange Stress Analysis Results: psi

	Operating		Gasket Seating	
	Actual	Allowed	Actual	Allowed
Tangential Flange	10576.62	20000.00	12146.52	20000.00
Bolting	16378.24	25000.00	0.00	25000.00

Minimum Required Flange Thickness [Rigidity]	3.893 in.
Estimated M.A.W.P. (Operating)	359.8 psig
Estimated Finished Weight of Flange at given Thk.	396.3 lbm
Estimated Unfinished Weight of Forging at given Thk	396.3 lbm

Flange Rigidity Based on Required Thickness [ASME]:

Flange Rigidity Index, Seating (rotation check) per APP. 2 [Js]:
= 109.4 * Ma / Bsc * Cnv_fac / (Eamb * t^3 * ln(K) * Kl)
= 109.4 * 48211/1 * 12/(29400000 * 3.893^3 * 0.182 * 0.2)
= 1.000 (should be <= 1)

Flange Rigidity Index Operating (rotation check) per APP. 2 [J]:
= 109.4 * Mo / Bsc * Cnv_fac / (Eop * tc^3 * ln(K) * Kl)
= 109.4 * 41980/1 * 12/(28324998 * 3.893^3 * 0.182 * 0.2)
= 0.904 (should be <= 1)

Flange Rigidity Based on Given Thickness [ASME]:

Flange Rigidity Index, Seating (rotation check) per APP. 2 [Js]:
= 109.4 * Ma / Bsc * Cnv_fac / (Eamb * t^3 * ln(K) * Kl)
= 109.4 * 48211/1 * 12/(29400000 * 4^3 * 0.182 * 0.2)
= 0.922 (should be <= 1)

Flange Rigidity Index Operating (rotation check) per APP. 2 [J]:
= 109.4 * Mo / Bsc * Cnv_fac / (Eop * tc^3 * ln(K) * Kl)
= 109.4 * 41980/1 * 12/(28324998 * 4^3 * 0.182 * 0.2)
= 0.833 (should be <= 1)

Required Fillet Weld Leg size for Slip on Flanges:

For Loose Slip on Flanges designed per 2-4 sketches (3-4c) [c]:
= min(tn, max(2 * tr, (1/4 inch or 6 mm)))
= min(0.438, max(2 * 0.349, (0.25)))
= 0.438 in.

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Internal Pressure Results Summary:

Element Thickness, Pressure, Diameter and Allowable Stress :

From	To	Int. Press + Liq. Hd psig	Nominal Thickness in.	Total Corr Allowance in.	Element Diameter in.	Allowable Stress(SE) psi	Element#
Lft Head		300	0.75	0.0625	32	18955	1
Channel		300	0.75	0.0625	32	16111.8	2
Flange 1		300	...	0.0625	32	17000	3
Shell		100	0.5	0.0625	32	17000	4
Flange 2		300	...	0.0625	32	17000	5
RT Channel		300	0.75	0.0625	32	16111.8	6
RT Head		100	0.75	0.0625	32	20000	7

Element Required Thickness and MAWP :

From	To	Design Pressure psig	M.A.W.P. Corroded psig	M.A.P. New & Cold psig	Minimum Thickness in.	Required Thickness in.	Element#
Lft Head		300	403.4	465.1	0.6875	0.52701	1
Channel		300	672.3	775.1	0.75	0.36496	2
Flange 1		300	359.8	359.8	4	3.893	3
Shell		100	455.6	521.5	0.5	0.15732	4
Flange 2		300	359.8	359.8	4	3.893	5
RT Channel		300	672.3	775.1	0.75	0.36496	6
RT Head		100	424.9	464.3	0.6875	0.20936	7

Summary of Heat Exchanger Maximum Allowable Working Pressures :

Note:
For Exchanger designs, the following values include MAWPs that consider the tubesheet, tubes, tube/tubesheet joint etc. These values were determined by iteration. Review the tubesheet analysis report for more information.

```
Shell Side MAWP     =          418.1 psig
Shell Side MAPnc    =          521.5 psig
Channel Side  MAWP  =          359.8 psig
Channel Side  MAPnc =          359.8 psig
```

Elements Suitable for Design Internal Pressure.

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Internal Pressure Calculation Results:

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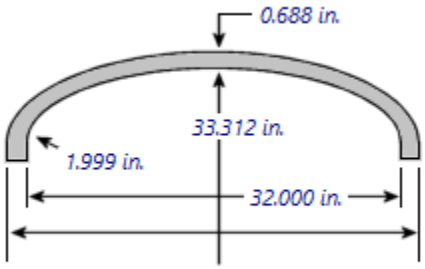

Internal Pressure Results for: Lft Head

Torispherical Head Design Information:			
Design Pressure P	300.000 psig	Int. Design Temperature	295 F
Material	SA-240 304	Ext. Design Temperature	295 F
Length	0.167 ft.	External Pressure Chart	HA-1
		UNS Number	S30400
Int. Corr. All. c	0.0625 in.	Allowable Stress (ope) S	18955.0 psi
Ext. Corr. All. ce	0.0000 in.	Allowable Stress (amb) Sa	20000.0 psi
Inside Diameter Di	32.000 in.	Actual Stress	14095.3 psi
Spec. Min. Thk t,e, or sa	0.6875 in.	Spec. Nominal Thk.	0.750 in.
Surface Area	1290.0 sq.in.	SG of Contents	0.000
Element Volume	4238.7 in3	Weight of Contents	0.0 lb.
Empty Weight	265.7 lb.	Operating Weight	265.7 lb.
Ins. Crn. Rad. L or R	33.3125 in.	Ins. Knuckle Radius r	1.999 in.
Radiography Information:			
User Defined		User Defined	
Circ. Joint Efficiency	85 %	Long. Joint Efficiency E	100 %

Tolerance for Formed Heads per UG-81(a):
Head inner surface maximum deviation outside the specified shape, 1.25% of D: 0.400 in.
Head inner surface maximum deviation inside the specified shape, 0.625% of D: 0.200 in.

Inside Corroded Head Depth [h]:
= L - sqrt((L - Di / 2) * (L + Di / 2 - 2 * r))
= 33.38-sqrt((33.38-32.12/2)*(33.38+32.12/2-2*2.061))
= 5.366 in.

M factor for Torispherical Heads (Corroded):
= (3+sqrt((L+C)/(r+C)))/4 per Appendix 1-4 (b & d)
= (3+sqrt((33.31 + 0.0625)/(1.999 + 0.0625)))/4
= 1.7560

Required Thickness due to Internal Pressure [tr]:
= (P*L*M)/(2*S*E-0.2*P) per Appendix 1-4 (d)
= (300*33.38*1.756)/(2*18955*1-0.2*300)
= 0.4645 + 0.0625 = 0.5270 in.

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
= (2*S*E*t)/(M*L+0.2*t) per Appendix 1-4 (d)
= (2*18955*1*0.625)/(1.756*33.38+0.2*0.625)
= 403.4 psig

M factor for Torispherical Heads (New & Cold):
= (3+sqrt(L/r))/4 per Appendix 1-4 (b & d)
= (3+sqrt(33.31/1.999))/4
= 1.7706

Maximum Allowable Pressure, New and Cold [MAPNC]:
= (2*S*E*t)/(M*L+0.2*t) per Appendix 1-4 (d)
= (2*20000*1*0.688)/(1.771*33.31+0.2*0.688)
= 465.1 psig

Actual stress at given pressure and thickness, corroded [Sact]:
= (P*(M*L+0.2*t))/(2*E*t)
= (300*(1.756*33.38+0.2*0.625))/(2*1*0.625)
= 14095.325 psi

Straight Flange Required Thickness:
= (P*R)/(S*E-0.6*P) + c per UG-27 (c)(1)
= (300*16.06)/(18955*1-0.6*300)+0.0625
= 0.319 in.

Straight Flange Maximum Allowable Working Pressure:
= (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
= (18955 * 1 * 0.688)/(16.06 + 0.6 * 0.688)
= 791 psig

% Elongation per Table UG-79-1 (75*tnom/Rf)*(1-Rf/Ro) 23.697 %
Note: Please Check Requirements of Table UHA-44 for Elongation limits.

SA-240 304, Min Metal Temp without impact per UHA-51: -320 F

Tolerance for Formed Heads per UG-81(a):
Head inner surface maximum deviation outside the specified shape, 1.25% of D: 0.400 in.
Head inner surface maximum deviation inside the specified shape, 0.625% of D: 0.200 in.

EXTERNAL PRESSURE RESULTS for: Lft Head

Torispherical Head From 10 to 20 Ext. Chart: HA-1 at 295 F

Elastic Modulus from Chart: HA-1 at 295 F: 26635000 psi

Results for Maximum Allowable Ext. Pressure				MAEP
Tca	Crown Rad	Ro/t	Factor A	Factor B
0.625	34.00	54.40	0.0022978	9773.12

MAEP = B/(Ro/t) = 9773/54.4 = 179.7 psig

Results for Required Thickness				Tca
Tca	Crown Rad	Ro/t	Factor A	Factor B
0.102	34.00	333.12	0.0003752	4997.22

MAEP = B/(Ro/t) = 4997/333.1 = 15 psig

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Internal Pressure Calculation Results:

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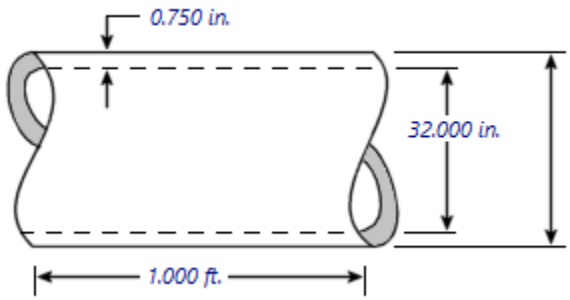

Internal Pressure Results for: Channel

Cylindrical Shell Design Information:			
Design Pressure P	300.000 psig	Int. Design Temperature	295 F
Material	SA-240 304	Ext. Design Temperature	295 F
Length	1.000 ft.	External Pressure Chart	HA-1
		UNS Number	S30400
Int. Corr. All. c	0.0625 in.	Allowable Stress (ope) S	18955.0 psi
Ext. Corr. All. ce	0.0000 in.	Allowable Stress (amb) Sa	20000.0 psi
Inside Diameter Di	32.000 in.	Actual Stress	8457.8 psi
Spec. Min. Thk t,e, or sa	0.7500 in.	Spec. Nominal Thk.	0.750 in.
Surface Area	1262.9 sq.in.	SG of Contents	0.000
Element Volume	9651.0 in3	Weight of Contents	0.0 lb.
Empty Weight	268.5 lb.	Operating Weight	268.5 lb.
Radiography Information:			
User Defined Circ. Joint Efficiency	85 %	User Defined Long. Joint Efficiency E	85 %

Required Thickness due to Internal Pressure [tr]:
= (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
= (300*16.06)/(18955*0.85-0.6*300)
= 0.3025 + 0.0625 = 0.3650 in.

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
= (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
= (18955*0.85*0.688)/(16.06+0.6*0.688)
= 672.3 psig

Maximum Allowable Pressure, New and Cold [MAPNC]:
= (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
= (20000*0.85*0.75)/(16+0.6*0.75)
= 775.1 psig

Actual stress at given pressure and thickness, corroded [Sact]:
= (P*(R+0.6*t))/(E*t)
= (300*(16.06+0.6*0.688))/(0.85*0.688)
= 8457.754 psi

% Elongation per Table UG-79-1 (50*tnom/Rf)*(1-Rf/Ro) 2.290 %
Note: Please Check Requirements of Table UHA-44 for Elongation limits.

SA-240 304, Min Metal Temp without impact per UHA-51: -320 F

EXTERNAL PRESSURE RESULTS for: Channel

Cylindrical Shell From 20 to 30 Ext. Chart: HA-1 at 295 F

Elastic Modulus from Chart: HA-1 at 295 F: 26635000 psi

Results for Maximum Allowable Ext. Pressure					MAEP	
Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.688	33.50	15.77	48.73	0.4707	0.0094087	11994.90

MAEP = (4*B)/(3*(Do/t)) = (4*11995)/(3*48.73) = 328.2 psig

Results for Required Thickness					Tca	
Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.081	33.50	15.77	411.32	0.4707	0.0003475	4627.50

MAEP = (4*B)/(3*(Do/t)) = (4*4628)/(3*411.3) = 15 psig

Results for Maximum Stiffened Length					Slen	
Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.688	33.50	995.05	48.73	29.7031	0.0004633	5905.10

MAEP = (4*B)/(3*(Do/t)) = (4*5905)/(3*48.73) = 161.6 psig

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Internal Pressure Calculation Results:

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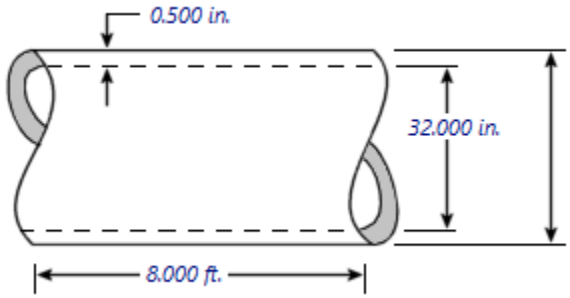

Internal Pressure Results for: Shell

Cylindrical Shell Design Information:			
Design Pressure P	100.000 psig	Int. Design Temperature	212 F
Material	SA-516 70	Ext. Design Temperature	212 F
Length	8.000 ft.	External Pressure Chart	CS-2
		UNS Number	K02700
Int. Corr. All. c	0.0625 in.	Allowable Stress (ope) S	20000.0 psi
Ext. Corr. All. ce	0.0000 in.	Allowable Stress (amb) Sa	20000.0 psi
Inside Diameter Di	32.000 in.	Actual Stress	4389.9 psi
Spec. Min. Thk t,e, or sa	0.5000 in.	Spec. Nominal Thk.	0.500 in.
Surface Area	9952.6 sq.in.	SG of Contents	0.000
Element Volume	62448.6 in3	Weight of Contents	0.0 lb.
Empty Weight	1372.2 lb.	Operating Weight	1372.2 lb.
Radiography Information:			
User Defined Circ. Joint Efficiency	85 %	User Defined Long. Joint Efficiency E	85 %

Required Thickness due to Internal Pressure [tr]:
= (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
= (100*16.06)/(20000*0.85-0.6*100)
= 0.0948 + 0.0625 = 0.1573 in.

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
= (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
= (20000*0.85*0.438)/(16.06+0.6*0.438)
= 455.6 psig

Maximum Allowable Pressure, New and Cold [MAPNC]:
= (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
= (20000*0.85*0.5)/(16+0.6*0.5)
= 521.5 psig

Actual stress at given pressure and thickness, corroded [Sact]:
= (P*(R+0.6*t))/(E*t)
= (100*(16.06+0.6*0.438))/(0.85*0.438)
= 4389.916 psi

% Elongation per Table UG-79-1 (50*tnom/Rf*(1-Rf/Ro)) 1.538 %

Minimum Design Metal Temperature Results:

Govrn. thk, tg = 0.5, tr = 0.0948, c = 0.0625 in., E✱ = 0.85
Thickness Ratio = tr * E✱/(tg - c) = 0.184, Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66, Curve B            -6 F
Min Metal Temp. at Required thickness (UCS 66.1)        -155 F
Min Metal Temp. w/o impact per UG-20(f)                  -20 F
```

MDMT Design Information:

MDMT Curve	B	Press. at MDMT	100.000 psig
UCS-66(b) red.	Yes	Min. Des. Mtl. Temp.	-20 F
Governing Thk.	0.500 in.	Basic MDMT	-6 F
Stress/Thk. Ratio	0.184	Temperature Difference	149 F
UCS-66(c) red.	No	Computed Min. Temp.	-155 F
		MDMT per UG-20(f)	-20 F
		Joint Efficiency E*	85 %

EXTERNAL PRESSURE RESULTS for: Shell

Cylindrical Shell From 40 to 50 Ext. Chart: CS-2 at 212 F

Elastic Modulus from Chart: CS-2 at 212 F: 29000000 psi

Results for Maximum Allowable Ext. Pressure — MAEP

Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.438	33.00	96.00	75.43	2.9091	0.0006945	10070.59

MAEP = (4*B)/(3*(Do/t)) = (4*10071)/(3*75.43) = 178 psig

Results for Required Thickness — Tca

Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.163	33.00	96.00	202.33	2.9091	0.0001570	2276.28

MAEP = (4*B)/(3*(Do/t)) = (4*2276)/(3*202.3) = 15 psig

Results for Maximum Stiffened Length — Slen

Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.438	33.00	2014.98	75.43	50.0000	0.0001933	2803.42

MAEP = (4*B)/(3*(Do/t)) = (4*2803)/(3*75.43) = 49.56 psig

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Internal Pressure Calculation Results:

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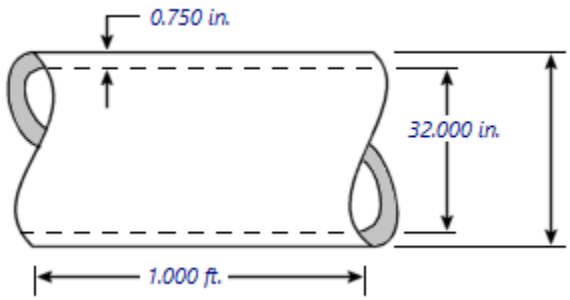

Internal Pressure Results for: RT Channel

Cylindrical Shell Design Information:			
Design Pressure P	300.000 psig	Int. Design Temperature	295 F
Material	SA-240 304	Ext. Design Temperature	295 F
Length	1.000 ft.	External Pressure Chart	HA-1
		UNS Number	S30400
Int. Corr. All. c	0.0625 in.	Allowable Stress (ope) S	18955.0 psi
Ext. Corr. All. ce	0.0000 in.	Allowable Stress (amb) Sa	20000.0 psi
Inside Diameter Di	32.000 in.	Actual Stress	8457.8 psi
Spec. Min. Thk t,e, or sa	0.7500 in.	Spec. Nominal Thk.	0.750 in.
Surface Area	1262.9 sq.in.	SG of Contents	0.000
Element Volume	9651.0 in3	Weight of Contents	0.0 lb.
Empty Weight	268.5 lb.	Operating Weight	268.5 lb.
Radiography Information:			
User Defined Circ. Joint Efficiency	85 %	User Defined Long. Joint Efficiency E	85 %

Required Thickness due to Internal Pressure [tr]:
= (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
= (300*16.06)/(18955*0.85-0.6*300)
= 0.3025 + 0.0625 = 0.3650 in.

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
= (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
= (18955*0.85*0.688)/(16.06+0.6*0.688)
= 672.3 psig

Maximum Allowable Pressure, New and Cold [MAPNC]:
= (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
= (20000*0.85*0.75)/(16+0.6*0.75)
= 775.1 psig

Actual stress at given pressure and thickness, corroded [Sact]:
= (P*(R+0.6*t))/(E*t)
= (300*(16.06+0.6*0.688))/(0.85*0.688)
= 8457.754 psi

% Elongation per Table UG-79-1 (50*tnom/Rf)*(1-Rf/Ro) 2.290 %
Note: Please Check Requirements of Table UHA-44 for Elongation limits.

SA-240 304, Min Metal Temp without impact per UHA-51: -320 F

EXTERNAL PRESSURE RESULTS for: RT Channel

Cylindrical Shell From 60 to 70 Ext. Chart: HA-1 at 295 F

Elastic Modulus from Chart: HA-1 at 295 F: 26635000 psi

Results for Maximum Allowable Ext. Pressure | MAEP

Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.688	33.50	15.77	48.73	0.4706	0.0094099	11995.05

MAEP = (4*B)/(3*(Do/t)) = (4*11995)/(3*48.73) = 328.2 psig

Results for Required Thickness | Tca

Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.081	33.50	15.77	411.34	0.4706	0.0003475	4627.71

MAEP = (4*B)/(3*(Do/t)) = (4*4628)/(3*411.3) = 15 psig

Results for Maximum Stiffened Length | Slen

Tca	Outer Dia	Slen	Do/t	L/D	Factor A	Factor B
0.688	33.50	994.96	48.73	29.7004	0.0004633	5905.10

MAEP = (4*B)/(3*(Do/t)) = (4*5905)/(3*48.73) = 161.6 psig

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Internal Pressure Calculation Results:

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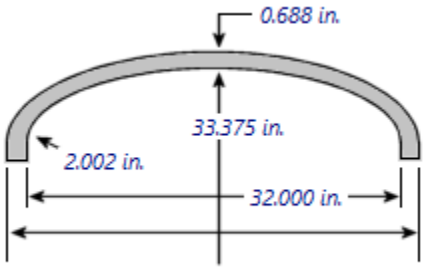

Internal Pressure Results for: RT Head

Torispherical Head Design Information:			
Design Pressure P	100.000 psig	Int. Design Temperature	295 F
Material	SA-516 70	Ext. Design Temperature	295 F
Length	0.167 ft.	External Pressure Chart	CS-2
		UNS Number	K02700
Int. Corr. All. c	0.0625 in.	Allowable Stress (ope) S	20000.0 psi
Ext. Corr. All. ce	0.0000 in.	Allowable Stress (amb) Sa	20000.0 psi
Inside Diameter Di	32.000 in.	Actual Stress	4707.3 psi
Spec. Min. Thk t,e, or sa	0.6875 in.	Spec. Nominal Thk.	0.750 in.
Surface Area	1290.0 sq.in.	SG of Contents	0.000
Element Volume	4237.8 in3	Weight of Contents	0.0 lb.
Empty Weight	256.5 lb.	Operating Weight	256.5 lb.
Ins. Crn. Rad. L or R	33.3750 in.	Ins. Knuckle Radius r	2.002 in.
Radiography Information:			
User Defined Circ. Joint Efficiency	85 %	User Defined Long. Joint Efficiency E	100 %

Tolerance for Formed Heads per UG-81(a):
Head inner surface maximum deviation outside the specified shape, 1.25% of D: 0.400 in.
Head inner surface maximum deviation inside the specified shape, 0.625% of D: 0.200 in.

Inside Corroded Head Depth [h]:
= L - sqrt((L - Di / 2) * (L + Di / 2 - 2 * r))
= 33.44-sqrt((33.44-32.12/2)*(33.44+32.12/2-2*2.065))
= 5.361 in.

M factor for Torispherical Heads (Corroded):
= (3+sqrt((L+C)/(r+C)))/4 per Appendix 1-4 (b & d)
= (3+sqrt((33.38 + 0.0625)/(2.002 + 0.0625)))/4
= 1.7560

Required Thickness due to Internal Pressure [tr]:
= (P*L*M)/(2*S*E-0.2*P) per Appendix 1-4 (d)
= (100*33.44*1.756)/(2*20000*1-0.2*100)
= 0.1469 + 0.0625 = 0.2094 in.

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
= (2*S*E*t)/(M*L+0.2*t) per Appendix 1-4 (d)
= (2*20000*1*0.625)/(1.756*33.44+0.2*0.625)
= 424.9 psig

M factor for Torispherical Heads (New & Cold):
= (3+sqrt(L/r))/4 per Appendix 1-4 (b & d)
= (3+sqrt(33.38/2.002))/4
= 1.7706

Maximum Allowable Pressure, New and Cold [MAPNC]:
= (2*S*E*t)/(M*L+0.2*t) per Appendix 1-4 (d)
= (2*20000*1*0.688)/(1.771*33.38+0.2*0.688)
= 464.3 psig

Actual stress at given pressure and thickness, corroded [Sact]:
= (P*(M*L+0.2*t))/(2*E*t)
= (100*(1.756*33.44+0.2*0.625))/(2*1*0.625)
= 4707.293 psi

Straight Flange Required Thickness:
= (P*R)/(S*E-0.6*P) + c per UG-27 (c)(1)
= (100*16.06)/(20000*1-0.6*100)+0.0625
= 0.143 in.

Straight Flange Maximum Allowable Working Pressure:
= (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
= (20000 * 1 * 0.688)/(16.06 + 0.6 * 0.688)
= 834.6 psig

Percent Elong. per UCS-79, VIII-1-01-57 (75*tnom/Rf)*(1-Rf/Ro) 23.659 %
Note: Please Check Requirements of UCS-79 as Elongation is > 5%.

MDMT Calculations in the Knuckle Portion:

Govrn. thk, tg = 0.688, tr = 0.147, c = 0.0625 in., E✱ = 1
Thickness Ratio = tr * E✱/(tg - c) = 0.235, Temp. Reduction = 140 F

Min Metal Temp. w/o impact per UCS-66, Curve B	11 F
Min Metal Temp. at Required thickness (UCS 66.1)	-155 F
Min Metal Temp. w/o impact per UG-20(f)	-20 F

MDMT Calculations in the Head Straight Flange:

Govrn. thk, tg = 0.75, tr = 0.0938, c = 0.0625 in., E✱ = 1
Thickness Ratio = tr * E✱/(tg - c) = 0.136, Temp. Reduction = 140 F

Min Metal Temp. w/o impact per UCS-66, Curve B	16 F
Min Metal Temp. at Required thickness (UCS 66.1)	-155 F
Min Metal Temp. w/o impact per UG-20(f)	-20 F

MDMT Design Information:

MDMT Curve	B	Press. at MDMT	100.000 psig
UCS-66(b) red.	Yes	Min. Des. Mtl. Temp.	-20 F
Governing Thk.	0.750 in.	Basic MDMT	16 F
Stress/Thk. Ratio	0.136	Temperature Difference	171 F
UCS-66(c) red.	No	Computed Min. Temp.	-155 F
		MDMT per UG-20(f)	-20 F

| Joint Efficiency E* 100 % |

Note: Temperature values displayed above are for the location with the highest basic MDMT

Tolerance for Formed Heads per UG-81(a):

Head inner surface maximum deviation outside the specified shape, 1.25% of D: 0.400 in.
Head inner surface maximum deviation inside the specified shape, 0.625% of D: 0.200 in.

EXTERNAL PRESSURE RESULTS for: RT Head

Torispherical Head From 70 to 80 Ext. Chart: CS-2 at 295 F

Elastic Modulus from Chart: CS-2 at 295 F: 29000000 psi

| Results for Maximum Allowable Ext. Pressure | MAEP |

Tca	Crown Rad	Ro/t	Factor A	Factor B
0.625	34.06	54.50	0.0022936	15478.99

MAEP = B/(Ro/t) = 15479/54.5 = 284 psig

| Results for Required Thickness | Tca |

Tca	Crown Rad	Ro/t	Factor A	Factor B
0.098	34.06	347.60	0.0003596	5214.37

MAEP = B/(Ro/t) = 5214/347.6 = 15 psig

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Hydrostatic Test Pressure Results:

Exchanger Shell Side Hydrostatic Test Pressures:

UG99(b)	= 1.30 * M.A.W.P. * Sa/S	543.526 psig
UG99b(b)(35)	= 1.30 * Design Pres * Sa/S	130.000 psig
UG99(c)	= 1.30 * M.A.P. - Head(Hyd)	676.759 psig
UG100	= 1.10 * M.A.W.P. * Sa/S	459.906 psig
PED	= max(1.43*DP, 1.25*DP*ratio)	143.000 psig
PED&UG99(b)(35)	= max(1.43*DP, 1.3*DP*ratio)	143.000 psig
App 27-4	= M.A.W.P.	418.097 psig

Exchanger Channel Side Hydrostatic Test Pressures:

UG99(b)	= 1.30 * M.A.W.P. * Sa/S	467.779 psig
UG99b(b)(35)	= 1.30 * Design Pres * Sa/S	130.000 psig
UG99(c)	= 1.30 * M.A.P. - Head(Hyd)	466.623 psig
UG100	= 1.10 * M.A.W.P. * Sa/S	395.813 psig
PED	= max(1.43*DP, 1.25*DP*ratio)	143.000 psig
PED&UG99(b)(35)	= max(1.43*DP, 1.3*DP*ratio)	143.000 psig
App 27-4	= M.A.W.P.	359.830 psig

UG-99(b)(35), Test Pressure Calculation [Shell Side]:
= Test Factor * Design Pressure * Stress Ratio
= 1.3 * 100 * 1
= 130.000 psig

UG-99(b) Note 35, Test Pressure Calculation [Channel Side]:
= Test Factor * Design Pressure * Stress Ratio
= 1.3 * 100 * 1
= 130.000 psig

Horizontal Test performed per: UG-99b (Note 35)

Please note that Nozzle, Shell, Head, Flange, etc MAWPs are all considered when determining the hydrotest pressure for those test types that are based on the MAWP of the vessel.

Stresses on Elements due to Test Pressure (psi & psig):

From To	Stress	Allowable	Ratio	Pressure
Lft Head	5639.3	27000.0	0.209	131.16
Channel	3384.3	27000.0	0.125	131.16
Shell	5030.2	34200.0	0.147	131.16
RT Channel	3384.3	27000.0	0.125	131.16
RT Head	5649.9	34200.0	0.165	131.16

Stress ratios for Pressurized Vessel Elements (psi):

Description	Ambient	Operating	Ratio
Lft Head	20000.00	18955.00	1.055
Channel	20000.00	18955.00	1.055
Flange 1	20000.00	20000.00	1.000
Shell	20000.00	20000.00	1.000
Flange 2	20000.00	20000.00	1.000
RT Channel	20000.00	18955.00	1.055
RT Head	20000.00	20000.00	1.000
Minimum			1.000

Stress ratios for Exchanger Materials (psi):

Description	Ambient	Operating	Ratio
Tube Material	11400.00	11400.00	1.000
Tubesheet Material	20000.00	20000.00	1.000
Minimum			1.000

Elements Suitable for Test Pressure.

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External Pressure Calculation Results Summary:

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External Pressure Calculations:

From	To	Section Length ft.	Outside Diameter in.	Corroded Thickness in.	Factor A	Factor B psi
10	20	No Calc	34	0.625	0.0022978	9773.12
20	30	1.31398	33.5	0.6875	0.0094087	11994.9
30	40	No Calc	...	3.9375	No Calc	No Calc
40	50	8	33	0.4375	0.00069452	10070.6
50	60	No Calc	...	3.9375	No Calc	No Calc
60	70	1.31384	33.5	0.6875	0.0094099	11995
70	80	No Calc	34.0625	0.625	0.0022936	15479

External Pressure Calculations:

From	To	External Actual T. in.	External Required T. in.	External Design Pressure psig	External M.A.W.P. psig
10	20	0.6875	0.16456	15	179.7
20	30	0.75	0.14395	15	328.2
30	40	4	3.293	15	No Calc
40	50	0.5	0.2256	15	178
50	60	4	3.293	15	No Calc
60	70	0.75	0.14394	15	328.2
70	80	0.6875	0.16049	15	284
Minimum					178

External Pressure Calculations:

From	To	Actual Length Bet. Stiffeners ft.	Allowable Length Bet. Stiffeners ft.	Ring Inertia Required in**4	Ring Inertia Available in**4
10	20	No Calc	No Calc	No Calc	No Calc
20	30	1.31398	82.921	No Calc	No Calc
30	40	No Calc	No Calc	No Calc	No Calc
40	50	8	167.915	No Calc	No Calc
50	60	No Calc	No Calc	No Calc	No Calc
60	70	1.31384	82.9137	No Calc	No Calc
70	80	No Calc	No Calc	No Calc	No Calc

Elements Suitable for External Pressure.

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Element and Detail Weights:

From	To	Element Metal Wgt. lb.	Element ID Volume in3	Corroded Metal Wgt. lb.	Corroded ID Volume in3	Extra due Misc % lb.
10	20	265.662	4238.73	244.645	4311.2	...
20	30	268.535	9650.97	246.627	9726.52	...
30	40	396.333	...	396.333	...	...
40	50	1372.25	62448.6	1203.03	63052.9	...
50	60	396.333	...	396.333	...	...
60	70	268.535	9650.97	246.627	9726.52	...
70	80	256.506	4237.8	236.213	4310.27	...
Total		3224	90227	2969	91127	0

For elements specified as shell side elements, the volume(s) shown above for those elements, reflects the displacement of the tubes.

Weight of Details:

From	Type	Weight of Detail lb.	X Offset, Dtl. Cent. ft.	Y Offset, Dtl. Cent. ft.	Z Offset Dtl. Cent. ft.	Description
30	FTsh	568.476	0.43333	...	...	Tubesheet
30	Tube	1196.49	4.1	...	...	Tubes
30	RTsh	568.476	7.76667	...	...	Tubesheet

Total Weight of Each Detail Type:

Exchanger Components	2333.4
Sum of the Detail Weights	2333.4 lb.

Weight Summation Results: (lb.)

	Fabricated	Shop Test	Shipping	Erected	Empty	Operating
Main Elements	3224.2	3224.2	3224.2	3224.2	3224.2	3224.2
Exchanger	2333.4	2333.4	2333.4	2333.4	2333.4	2333.4
Test Liquid	...	3258.2	...	...	...	...
Tube Tst Lqd	...	347.0	...	...	...	...
Totals	5557.6	9162.8	5557.6	5557.6	5557.6	5557.6

Weight Summary:

Fabricated Wt.	- Bare weight without removable internals	5557.6 lb.
Shop Test Wt.	- Fabricated weight + water (full)	9162.8 lb.
Shipping Wt.	- Fab. weight + removable intls.+ shipping app.	5557.6 lb.
Erected Wt.	- Fab. wt + or - loose items (trays,platforms etc.)	5557.6 lb.
Ope. Wt. no Liq	- Fab. weight + internals. + details + weights	5557.6 lb.
Operating Wt.	- Empty weight + operating liq. uncorroded	5557.6 lb.
Oper. Wt. + CA	- Corr wt. + operating liquid	5303.3 lb.

Exchanger Tube Data

Volume of Exchanger tubes :	9608.9 in3

```
 Weight of Ope Liq in tubes :                    0.0 lb.
 Weight of Water in tubes   :                  347.0 lb.
```

The Corroded Weight and thickness are used in the Horizontal Vessel Analysis (Ope Case) and Earthquake Load Calculations.

Surface Areas of Elements:

From	To	Outside Surface Area sq.in.	Inside Surface Area sq.in.
10	20	1290.02	1154.02
20	30	1262.92	1206.37
30	40	836.418	402.124
40	50	9952.57	9650.97
50	60	836.418	402.124
60	70	1262.92	1206.37
70	80	1290.04	1154.04
Total		16731.3	15176.0 sq.in.
Total		116.2	105.4 ft^2

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Shop/Field Installation Options :

Note : The CG is computed from the first Element From Node

Center of Gravity of the Tubesheet(s)	5.287 ft.
Center of Gravity of the Tubes	5.287 ft.
Center of Gravity of Bare Shell New and Cold	5.339 ft.
Center of Gravity of Bare Shell Corroded	5.339 ft.
Vessel CG in the Operating Condition	5.316 ft.
Vessel CG in the Fabricated (Shop/Empty) Condition	5.317 ft.

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Input Echo, Tubesheet Number 1, Description: Tubesheet

Shell Data:

Main Shell Description: Shell

Shell Maximum Design Pressure	Psd,max	100.00	psig
Shell Maximum Operating Pressure	Psox,max	100.00	psig
Shell Minimum Operating Pressure	Psox,min	0.00	psig
Shell Thickness	ts	0.5000	in.
Shell Internal Corrosion Allowance	cas	0.0625	in.
Shell External Corrosion Allowance	casext	0.0000	in.
Inside Diameter of Shell	Ds	32.000	in.
Shell Circumferential Joint Efficiency	Esw	0.850	
Shell Temperature for Internal Pressure	Ts	212.00	F
Shell Material		SA-516 70	

See ASME VIII Div. 1, UG-23(e), for determination of the SPS allowable.

Shell Material UNS Number		K02700	
Shell Allowable Stress at Temperature	Ss	20000.00	psi
Shell Allowable Stress at Ambient		20000.00	psi

Channel Description: Channel

Channel Type:		Cylinder	
Channel Maximum Design Pressure	Ptd,max	300.00	psig
Channel Maximum Operating Pressure	Ptox,max	300.00	psig
Channel Minimum Operating Pressure	Ptox,min	0.00	psig
Channel Thickness	tc	0.7500	in.
Channel Internal Corrosion Allowance	cac	0.0625	in.
Channel External Corrosion Allowance	cacext	0.0000	in.
Inside Diameter of Channel	Dc	32.000	in.
Channel Design Temperature	TEMPC	295.00	F
Channel Flange Matl		SA-240 304	

See ASME VIII Div. 1, UG-23(e), for determination of the SPS allowable.

Channel Material UNS Number		S30400	
Channel Allowable Stress at Temperature	Sc	18955.00	psi
Channel Allowable Stress at Ambient		20000.00	psi

Tube Data:

Number of Tube Holes	Nt	348	
Tube Wall Thickness	et	0.0625	in.
Tube Outside Diameter	D	0.7500	in.
Total Straight Tube Length	Lt	90.00	in.
Straight Tube Length (bet. inner tubsht faces)	L	86.00	in.
Design Temperature of the Tubes		295.00	F
Tube Material		SA-214	
Tube Material UNS Number		K01807	
Is this a Welded Tube		No	
Tube Material Specification used		Wld. tube	
Tube Allowable Stress at Temperature		11400.00	psi
Tube Allowable Stress At Ambient		11400.00	psi
Tube Yield Stress At design Temperature	Syt	23040.00	psi
Tube Pitch (Center to Center Spacing)	P	1.1250	in.
Tube Layout Pattern		Triangular	
Fillet Weld Leg	af	0.0000	in.
Groove Weld Leg	ag	0.0000	in.
Tube-Tubesheet Joint Weld Type		Seal/No Weld	
Method for Tube-Tubesheet Jt. Allowable		UW-20.4.2	
Tube-Tubesheet Joint Classification		i	

Is Tube-Tubesheet Joint Tested		No	
ASME Tube Joint Reliability Factor	fr	0.70	
Interface Pressure, after tube expansion	Po	0.00	psig
Interface Pressure, due to diff. thermal exp.	PT	0.00	psig
Radius to Outermost Tube Hole Center	ro	12.000	in.
Largest Center-to-Center Tube Distance	Ul	0.0000	in.
Length of Expanded Portion of Tube	ltx	1.5000	in.
Tube-side pass partition groove depth	hg	0.0000	in.

Tubesheet Data:

Tubesheet TYPE: Fixed Tubesheet Exchanger, Conf B

Tubesheet Design Metal Temperature	T	295.00	F
Tubesheet Material		SA-516 70	

See ASME VIII Div. 1, UG-23(e), for determination of the SPS allowable.

Tubesheet Material UNS Number		K02700	
Tubesheet Allowable Stress at Temperature	S	20000.00	psi
Tubesheet Allowable Stress at Ambient	Tt	20000.00	psi
Thickness of Tubesheet	h	2.0000	in.
Tubesheet Corr. Allowance (Shell side)	Cats	0.0625	in.
Tubesheet Corr. Allowance (Channel side)	Catc	0.0625	in.
Tubesheet Outside Diameter	A	38.400	in.

Additional Data for Stepped Tubesheets:

Is the Tubesheet Stepped?		No	
Area of the Untubed Lanes	AL	0.000	sq.in.

Additional Data for Fixed/Floating Tubesheet Exchangers:

Unsupported Tube Span under consideration	l	12.000	in.
Tube End condition corresponding to Span (l)	k	1.00	
Tubesheet Metal Temp. at Rim	T'	70.00	F
Shell Metal Temp. at Tubesheet	T'S	212.00	F
Channel Metal Temp. at Tubesheet	T'C	295.00	F
Perform Differential Pressure Design		No	
Run Multiple Load Cases		Yes	
Mean Shell Metal Temp. along Shell len.	Tsm	180.00	F
Mean Tube Metal Temp. along Tube length	Ttm	248.00	F
Junction Stress Reduction option		Perform Plastic Calculation	

Additional Data for Gasketed Tubesheets:

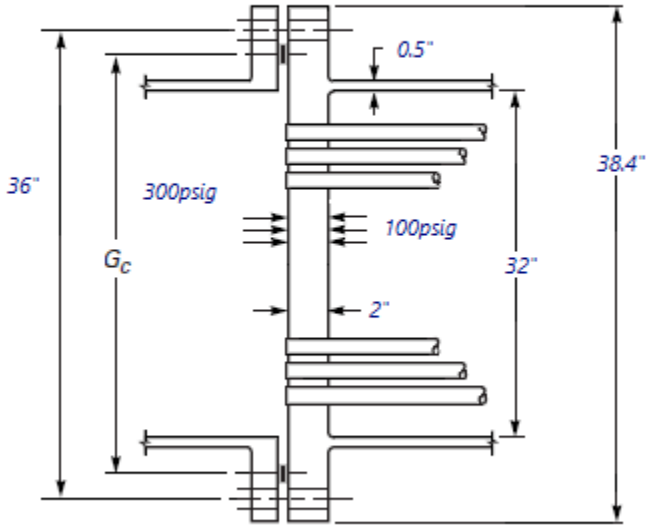
Tubesheet Gasket on which Side		Channel	
Flange Outside Diameter	A	38.400	in.
Flange Inside Diameter	B	32.000	in.
Flange Face Outside Diameter	Fod	33.000	in.
Flange Face Inside Diameter	Fid	32.000	in.
Gasket Outside Diameter	Go	32.750	in.
Gasket Inside Diameter	Gi	32.000	in.
Gasket Factor,	m	0.50	
Gasket Design Seating Stress	y	0.00	psi
Flange Facing Sketch		Code Sketch 1a	
Column for Gasket Seating		Code Column II	
Gasket Thickness	tg	0.1250	in.
Full face Gasket Flange Option		Program Selects	

Bolting Information:

Diameter of Bolt Circle	C	36.000	in.
Nominal Bolt Diameter	dB	1.0000	in.

Thread Series		TEMA Thread Series	
Number of Bolts	n	28	
Bolt Material		SA-193 B7	
Bolt Allowable Stress At Temperature	Sb	25000.00	psi
Bolt Allowable Stress At Ambient	Sa	25000.00	psi
Weld between Flange and Shell/Channel		0.0000	in.
Tubesheet Integral with		Shell	
Tubesheet Extended as Flange		Yes	
Thickness of Extended Portion of Tubesheet	Tf	2.0000	in.
Is Bolt Load Transferred to the Tubesheet		Yes	
Is Exchanger in Creep range (skip EP, Use 3S for Sps)		No	

Tubesheet Integral w/Shell, Gasketed w/Channel, Extended as a Flange



Configuration b:

Messages regarding the Tubesheet & Exchanger Input Data:

Note - Tube-Tubesheet Joint Interface pressures are 0, its effect will be ignored [UW-20.3/4.21.2].

ASME TubeSheet Results per Part UHX/4.18, 2023

Elasticity/Expansion Material Properties:

Shell - TE-1 Carbon & Low Alloy Steels, Group 1
Shell - TM-1 Carbon Steels with C<= 0.3%

Th. Exp. Coeff. Metal Temp. along Len	180.0 F	0.0000066600	/F
Elastic Mod. at Design Temperature	212.0 F	0.28740E+08	psi
Th. Exp. Coeff. Metal Temp. at Tubsht	212.0 F	0.0000067240	/F
Elastic Mod. at Metal Temp. along Len	180.0 F	0.28892E+08	psi
Elastic Mod. at Ambient Temperature	70.0 F	0.29400E+08	psi

Channel - TE-1 Austenitic Group 3 Steels
Channel - TM-1 Material Group G

```
 Th. Exp. Coeff. Metal Temp. at Tubsht   295.0 F       0.0000091900 /F
 Elastic Mod. at Design Temperature      295.0 F       0.27025E+08 psi
 Elastic Mod. at Ambient Temperature      70.0 F       0.28300E+08 psi
```

Tubes - TE-1 Carbon & Low Alloy Steels, Group 1
Tubes - TM-1 Carbon Steels with C<= 0.3%

```
 Th. Exp. Coeff. Metal Temp. along Len   248.0 F       0.0000067960 /F
 Elastic Mod. at Design Temperature      295.0 F       0.28325E+08 psi
 Elastic Mod. at Metal Temp. along Len   248.0 F       0.28560E+08 psi
 Elastic Mod. at Tubsht. Design Temp.    295.0 F       0.28325E+08 psi
 Elastic Mod. at Ambient Temperature      70.0 F       0.29400E+08 psi
```

TubeSheet - TE-1 Carbon & Low Alloy Steels, Group 1
TubeSheet - TM-1 Carbon Steels with C<= 0.3%

```
 Th. Exp. Coeff. Metal Temp. at Rim       70.0 F       0.0000064000 /F
 Elastic Mod. at Design Temperature      295.0 F       0.28325E+08 psi
 Elastic Mod. at Metal Temp. at Rim       70.0 F       0.29400E+08 psi
 Elastic Mod. at Ambient Temperature      70.0 F       0.29400E+08 psi
```

Note:
The Elasticity and Alpha values are taken from Tables in ASME II D.
Please insure these properties are consistent with the
type of Material for the tubes, shell, channel etc.

Tube Required Thickness under Internal Pressure (Tubeside pressure):
Thickness Due to Internal Pressure:

```
  = (P*(D/2-CAE)) / (S*E+0.4*P) per Appendix 1-1 (a)(1)
  = (300*(0.75/2-0)/(11400*1+0.4*300)
  = 0.0098 + 0.0000 = 0.0098 in.
```

Tube Required Thickness under External Pressure (Shellside pressure) :

```
 External Pressure Chart     CS-1             at       295.00  F
 Elastic Modulus for Material                     29000000.00  psi
```

Results for Max. Allowable External Pressure (Emawp):

```
     TCA        ODCA      SLEN       D/T       L/D    Factor A        B
   0.0625       0.75     86.00     12.00    50.0000  0.0076389      13895.75
 EMAWP = (4*B)/(3*(D/T)) = ( 4 *13896 )/( 3 *12 ) = 1544 psig
```

Results for Reqd Thickness for Ext. Pressure (Tca):

```
     TCA        ODCA      SLEN       D/T       L/D    Factor A        B
   0.0126       0.75     86.00     59.69    50.0000  0.0003087       4476.81
 EMAWP = (4*B)/(3*(D/T)) = ( 4 *4477 )/( 3 *59.69 ) = 100 psig
```

Summary of Tube Required Thickness Results:

```
 Total Required Thickness including Corrosion all.        0.0126 in.
 Allowable Internal Pressure at Corroded thickness       2035.71 psig
 Required Internal Design Pressure                        300.00 psig
 Allowable External Pressure at Corroded thickness       1543.97 psig
 Required External Design Pressure                        100.00 psig
 Required Thickness due to Shell Side pressure            0.0126 in.
```

Detailed Results for load Case D3 un-corr. (Psd,max + Ptd,max)

Intermediate Calculations For Tubesheets Extended As Flanges:

ASME Code, Section VIII Division 1, 2023

```
 Gasket Contact Width,       N = (Goc-Gic) / 2            0.375 in.
 Basic Gasket Width,        b0 = N / 2                    0.188 in.
 Effective Gasket Width,     b = b0                       0.188 in.
 Gasket Reaction Diameter,   G = (Go+Gi) / 2             32.375 in.
```

Results for ASME Fixed Tubesheet Calculations for Configuration b:

Results for Tubesheet Calculations Original Thickness:

ASME Section VIII-2 Part 4.18.8.4 Step 1:

Compute the tube expansion depth ratio [rho]:

```
  = ltx / h  ( modified for corrosion if present )
  = 1.5/2
  = 0.7500 ( must be 0 <= rho <= 1 )
```

Compute the effective tube hole diameter [d✱]:

```
  = max( dt - 2 * tt( EtT/E ) * ( StT/S ) * ( rho ); dt - 2 * tt)
  = max( 0.75 - 2 * 0.0625 ( 28324998/28324998 ) *
    ( 11400/20000 ) * (0.75 ); 0.75 - 2 * 0.0625 )
  = 0.6966 in.
```

Compute the equivalent outer tube limit circle diameter [Do]:

```
  = 2 * ro + dt
  = 2 * 12 + 0.75
  = 24.750 in.
```

Determine the basic ligament efficiency for shear [mu]:

```
  = ( p - dt ) / p
  = ( 1.125 - 0.75 )/1.125
  = 0.333
```

Compute the equivalent outer tube limit radius [ao]:

```
  = Do / 2
  = 24.75/2
  = 12.3750 in.
```

Compute the effective tube pitch [p✱]:

```
  = p / sqrt( 1 - 4 * min( AL * CNV_factor; 4 * Do * p)/( pi * Do^2) )
  = 1.125/sqrt( 1 - 4 * min( 0 * 1 ; 4 * 24.75 * 1.125 )/( pi * 24.75^2) )
  = 1.1250 in.
```

Compute the effective ligament efficiency for bending [mu✱]:

```
  = ( p✱ - d✱) / p✱
  = ( 1.125 - 0.697 )/1.125
  = 0.3808
```

Compute the ratio [Rhos]:

```
  = as / ao
  = 16/12.38
  = 1.2929
```

Compute the ratio [Rhoc]:

```
  = ac / ao
  = 16.19/12.38
  = 1.3081
```

Compute parameter [xt]:

```
  = 1 - Nt( ( dt - 2 * tt )/( 2 * ao ) )^2
  = 1 - 348 ( ( 0.75 - 2 * 0.0625 )/( 2 * 12.38 ) )^2
```

= 0.7781

Determine parameter [xs]:
= 1 - Nt(dt/(2 * ao))^2
= 1 - 348 (0.75/(2 * 12.38))^2
= 0.6804

Determine the value [h'g]:
= max((hg - CATC); 0) (For pressure only cases)
= max((0 - 0); 0)
= 0.000 in.

ASME Section VIII-2 Part 4.18.8.4 Step 2:

Determine the Axial Shell Stiffness [Ks]:
= pi * ts(Ds + ts)Es/L
= pi * 0.5 (32 + 0.5)28740000/86
= 17060492.0000 lb./in.

Determine the Axial Tube Stiffness [Kt]:
= pi * tt(Dt - tt)Et/L
= pi * 0.0625 (0.75 - 0.0625)28324998/86
= 44460.4727 lb./in.

Compute the Stiffness Factor [Ks,t]:
= Ks / (Nt * Kt)
= 17060492/(348 * 44460)
= 1.10265

Rigidty Ratio [J]:
= 1 / (1 + Ks/Kj)
= 1/(1 + 17060492/0)
= 1.0000 (= 1 if No Exp. Jt.)

Compute shell coefficient [betas]:
= ((12(1 - nu_s^2))$^{0.25}$)/sqrt((Ds + ts)ts)
= ((12(1 - 0.3^2))$^{0.25}$)/sqrt((32 + 0.5)0.5)
= 0.4510 1/in.

Determine shell coefficient [ks]:
= betas * Es * ts^3 / (6(1 - nu_s^2))
= 0.451 * 28740000 * 0.5^3/(6(1 - 0.3^2))
= 296710.6250 psig*in.^2

Determine shell coefficient [lambdas]:
= 6(Ds + ts) * ks/h^3 * (1 + h * betas + (h * betas)^2/2)
= 6(32 + 0.5) * 296711/2^3 * (1 + 2 * 0.451 + (2 * 0.451)^2/2)
= 16696639.0000 psig

Determine shell coefficient [deltas]:
= Ds^2/(4 * Es * ts) * (1 - Ds * nu_s/(2(Ds + ts)))
= 32^2/(4 * 28740000 * 0.5) * (1 - 32 * 0.3/(2(32 + 0.5)))
= 0.15184E-04 in./psi

Intermediate parameters for Tubesheet Gasketed on the Channel Side:
betaC, kc, lambdaC, deltaC are all = 0

ASME Section VIII-2 Part 4.18.8.4 Step 3:

SME Section VIII-2 Part 4.18.8.4 Step 3:
h/p = 1.777778 ; mu* = 0.380833 ; E* = 11242843 psi
E*/E = 0.396923 ; nu* = 0.310175

Compute the Tube Bundle Stiffness Factor [Xa]:
= ((24(1 - nu✱^2)Nt * Et * tt(dt - tt)ao^2)/(E✱ * L * H^3))$^{0.25}$
= ((24(1-0.31^2)348 * 28324998 * 0.0625
(0.75 - 0.0625)12.38^2)/(11242843 * 86 * 2^3))$^{0.25}$
= 3.6724

Values from Table 4.18.3
Zd = 0.031149 ; Zv = 0.076156 ; Zm = 0.412984
Za = 0.453318E+01 ; Zw = 0.076156

ASME Section VIII-2 Part 4.18.8.4 Step 4:

Compute the diameter ratio [K]:
= A / Do
= 38.4/24.75
= 1.5515

Compute coefficient [F]:
= (1 - nu✱)/ E✱ * (lambdas + lambdac + E * ln(K))
= (1 - 0.31)/11242843 * (16696639 + 0 +
28324998 * ln(1.552))
= 1.7878

Compute parameter [Phi]:
= (1 + nu✱)F
= (1 + 0.31)1.788
= 2.3423

Compute parameter [Q1]:
= (Rhos - 1 - Phi * Zv)/(1 + Phi * Zm)
= (1.293 - 1 - 2.342 * 0.0762)/(1 + 2.342 * 0.413)
= 0.058224

Compute Parameter [Qz1]:
= (Zd + Q1 * Zw)/2 * Xa^4
= (0.0311 + 0.0582 * 0.0762)/2 * 3.672^4
= 3.2360

Compute parameter [Qz2]:
= (Zv + Q1 * Zm)/2 * Xa^4
= (0.0762 + 0.0582 * 0.413)/2 * 3.672^4
= 9.1128

Compute parameter [U]:
= (Zw + (Rhos - 1)Zm)Xa^4 / (1 + Phi * Zm)
= (0.0762 + (1.293 - 1)0.413)3.672^4/(1 + 2.342 * 0.413)
= 18.2256

ASME Section VIII-2 Part 4.18.8.4 Step 5:

Determine factor [gammab]:
= (Gc - C) / Do (config b)
= (32.38 - 36)/24.75 = -0.146

Compute Parameter [gamma]:
= 0.000 in. (For Pressure only cases)

Calculate parameter [omegas]:
= rhos * ks * betas * deltaS(1 + h * betas)
= 1.293 * 296711 * 0.451 * 0.15184E-04 (1 + 2 * 0.451)
= 4.9958 in.^2

Calculate parameter [omega✱s]:
```
  = ao^2( rhos^2 - 1 ) * ( rhos - 1 ) / 4 - omegas
  = 12.38^2( 1.293^2 - 1 ) * ( 1.293 - 1 )/4 - 4.996
  = 2.5368 in.^2
```

Calculate parameter [omegac]:
```
  = 0 because betaC is equal to zero
```

Calculate parameter [omega✱c]:
```
  = ao^2[ ( Rhoc^2 + 1 ) * ( Rhoc - 1 )/4 - ( Rhos - 1 )/2 ] - omegac
  = 12.38^2[ ( 1.308^2 + 1 ) * ( 1.308 - 1 )/4 - ( 1.293 - 1 )/2 ] - 0
  = 9.5472 in.^2
```

Compute the pressure [P✱S]:
= 0 For Pressure only cases or Configurations d,e,f,A,B,C,D

Compute the pressure [P✱C]:
= 0 For Pressure only cases or Configurations b,c,d,B,C,D

ASME Section VIII-2 Part 4.18.8.4 Step 6:

Compute the pressure [P's]:
```
  = Ps{ xs + 2( 1 - xs )nu_t + [2/Kst * (Ds/Do)^2]nu_s -
    [( rhos^2 - 1 )/( J*Kst )]-[( 1 - J )/( 2J * Kst )][( Dj^2 - (Ds)^2 )/Do^2] }
  = 100 { 0.68 + 2( 1 - 0.68 )0.3 + [2/1.103 *
    (32/24.75 )^2]0.3 - [( 1.293^2 - 1 )/( 1 * 1.103 )] -
   [( 1 - 1 )/( 2 * 1 * 1.103 )][( 0^2 - (32 )^2 )/24.75^2] }
  = 117.2664 psig
```

Compute the pressure [P't]:
```
  = [ xt + 2( 1 - xt )nu_t + 1/( J * Kst ) ]Pt
  = [ 0.778 + 2( 1 - 0.778 )0.3 + 1/( 1 * 1.103 ) ]300
  = 545.4415 psig
```

Compute the pressure [P_(gamma)]:
```
  = Nt * Kt * gamma / ( pi * ao^2 )
  = 348 * 44460 * 0/( 3.142 * 12.38^2 )
  = 0.0000 psig
```

Compute the pressure [Pw]:
```
  = -gammab * U * W✱ / ( 2 * pi * ao^2 )
  = --0.146 * 18.23 * 252683/( 2 * pi * 12.38^2 )
  = 701.0034 psig
```

Calculate the pressure [Prim]:
```
  = -( U/ao^2 ) * ( omega✱s * Ps - omega✱c * Pt )
  = -( 18.23/12.38^2 ) * ( 2.537 * 100 - 9.547 * 300 )
  = 310.6789 psig
```

Calculate the pressure [POmega]:
```
  = ( U/ao^2 ) * ( omegas * P✱s - omegac * P✱c )
  = ( 18.23/12.38^2 ) * ( 4.996 * 0 - 0 * 0 )
  = 0.0000 psig
```

Determine the effective pressure [Pe]:
```
  = J * Kst / ( 1 + J * Kst( Qz1 + ( Rhos - 1 )Qz2 ) ) *
    ( P's - P't + Pgama + Pomega + Pw + Prim )
  = 0.1000E+01 * 1.103/( 1 + 1 * 1.103 ( 3.236 + ( 1.293 -
    1 )9.113 ) ) * ( 117.3 - 545.4 + 0 + 0 + 701 + 310.7 )
  = 85.6543 psig
```

ASME Section VIII-2 Part 4.18.8.4 Step 7:

Determine factor [Q2]:

```
= [ ( ( omega*s * Ps - omega*c * Pt ) - ( omegas * P*s - omegac * P*c ) ) +
  W* * gammab / ( 2 * pi ) ]/( 1 + Phi * Zm )
= [ ( ( 2.537 * 100 - 9.547 * 300 ) -
  ( 4.996 * 0 - 0 * 0 ) ) * 1 +
  252683 * -0.146/( 2 * pi ) ]/( 1 + 2.342 * 0.413 )
= -4320.8828 lb.
```

Calculate factor [Q3]:

```
= Q1 + 2 * Q2 / ( Pe * ao^2 )
= 0.0582 + 2 * -4321/( 85.65 * 12.38^2 )
= -0.60059
```

Fm Value from Table 4.18.3 = 0.300295

Tubesheet Bending Stress - original thickness [Sigma]:

```
= ( 1.5 * Fm / mu* ) * ( 2 * ao/( H - h'g ) )^2 * Pe
= ( 1.5 * 0.3/0.381 ) * ( 2 * 12.38/( 2 - 0 ) )^2 * 85.65
= 15514.7383 psi
```

Allowable Tubesheet Bending Stress [Sigma allowed]:

```
= 1.5 * S = 1.5 * 20000 = 30000 psi
```

Tubesheet Bending Stress - final thickness [Sigmaf]:

```
= ( 1.5 * Fm / mu* ) * ( 2 * ao/( h - h'g ) )^2 * Pe
= ( 1.5 * 0.14/0.381 ) * ( 2 * 12.38/( 1.269 - 0 ) )^2 * 142.6
= 29998.8613 psi
```

Reqd Tubesheet Thickness, for Bending Stress (including CA) [HReqB]:

```
= h + Cats + Catc
= 1.269 + 0 + 0
= 1.2690 in.
```

ASME Section VIII-2 Part 4.18.8.4 Step 8:

Shear Stress check [Tau_(limit)]:

```
= ( 2 * mu * h / ao ) * min( 0.8S; 0.533Sy )
= ( 2 * 0.333 * 2/12.38 ) * 16000
= 1723.9058 psi
```

Shear Stress is not required to be computed; [Pe] <= Tau_limit

Tubesheet Shear Stress - final thickness [Tauf]:

```
= ( 1/( 2 * mu ) ) * ( ao/h ) * Pe
= ( 1/( 2 * 0.333 ) ) * ( 12.38/0.236 ) * 195.9
= 15427.1426 psi
```

Reqd Tubesheet Thickness, for Shear Stress (including CA) [HreqS]:

```
= H + Cats + Catc
= 0.236 + 0 + 0
= 0.2357 in.
```

Reqd Tubesheet Thickness for Given Loadings (including CA) [Hreqd] :

```
= max( HreqB; HreqS )
= max( 1.269 ; 0.236 )
= 1.2690 in.
```

ASME Section VIII-2 Part 4.18.8.4 Step 9:

The Ftmin and Ftmax Coefficients from Table 4.18.4:

```
  Ftmin = -1.327, Ftmax = 1.87
```

First Extreme Tube Axial Stress from among all the tubes [Sigmat1]:
```
  = ( ( Ps * xs - Pt * xt ) - Pe * Ftmin ) / ( Xt - Xs )
  = ( ( 100 * 0.68 - 300 * 0.778 ) - (85.65 ) * -1.327 )/
    ( 0.778 - 0.68 ) )
  = -529.7640 psi
```

Second Extreme value of Tube Axial Stress from among all the tubes [Sigmat2]:
```
  = ( ( Ps * xs - Pt * xt ) - Pe * Ftmax ) / ( Xt - Xs )
  = ( ( 100 * 0.68 - 300 * 0.778 ) - (85.65 ) * 1.87 )/
    ( 0.778 - 0.68 ) )
  = -3333.9092 psi
```

Maximum Tube Axial Stress [Sigmat,max]:
```
  = max( | Sigmat,1 |; | Sigmat,2 | ) = 3334 psi
```

Allowable Tube Stress [Sigmat,A]:
```
  = Sot = 11400.0000 psi
```

Check for Buckling as some of the tubes are in compression.

Determine the Factor of Safety [Fs]:
```
  = max( ( 3.25 - 0.25( Zd + Q3 * Zw )Xa^4 ); 1.25 )
  = max( ( 3.25 - 0.25( 0.0311 + -0.601 * 0.0762 )3.672^4 ); 1.25 )
  = 2.0000  (Should be <= 2 )
```

Determine the factor [rt]:
```
  = ( sqrt( dt^2 + ( dt - 2 * tt )^2 ) )/4
  = ( sqrt( 0.75^2 + ( 0.75 - 2 * 0.0625 )^2 ) )/4
  = 0.2441 in.
```

Determine the factor [Ct]:
```
  = sqrt( 2 * pi^2 * Et/Syt )
  = sqrt( 2 * pi^2 * 28324998/23040 )
  = 155.7789
```

Determine the factor [Ft]:
```
  = k * L/r
  = 1 * 12/0.244
  = 49.1662
```

Buckling Allowable Stress [Stb]:
```
  = ( Sy,t/Fs ) * ( 1 - Ft/( 2 * Ct ) )
  = ( 23040/2 ) * ( 1 - 49.17/( 2 * 155.8 ) )
  = 9702.058 psi    (Never greater than Sot)
```

Note: The Axial Compressive stress in tubes is within limits.

Largest tube-to-tubesheet Joint Load [Wt]:
```
  = Sigmat,max * Tube Area
  = 3334 * 0.135
  = 450.05 lb.
```

Tube Metal Area [At]:
```
  = pi( do - t )t
  = pi( 0.75 - 0.0625 )0.0625
  = 0.135 sq.in.
```

Allowable Tube-To-Tubesheet Load per ASME VIII-1 UW-20 [Lmax]:
```
  = min( At * Sa * fr * fe * fy * ft; At * Sa )
  = min( 0.135 * 11400 * 0.7 * 1 * 1 * 1 ; 0.135 * 11400 )
  = 1077.2 lb.
```

ASME Section VIII-2 Part 4.18.8.4 Step 10:

Shell Axial Membrane Allowable Stress:
```
= Ss * Esw = 20000 * 0.85 = 17000 psi
```

Axial Membrane Stress in Shell [Sigmas,m]:
```
= ao^2/( (Ds+ts)ts ) * [Pe + (Rhos^2-1)(Ps-Pt)] + as^2*Pt/( (Ds+ts)ts )
= 12.38^2/( (32 +0.5 )0.5 ) * [85.65 + (1.293^2-1)
  (100 -300 )] + 16^2*300/( (32 +0.5 )0.5 )
= 4267.4014 psi
```

ASME Section VIII-2 Part 4.18.8.4 Step 11:

Note:
For a given Shell thickness of 0.5 in., the minimum Shell
length adjacent to the tubesheet should be 7.200 in.

Shell Membrane Stress due to Joint Interaction [Sigmas,m]:
```
= ao^2/( ( Ds+ts )ts )[ Pe + ( rhos^2-1 )( Ps-Pt ) ] + as^2*Pt/( ( Ds+ts )ts )
= 12.38^2/( ( 32 +0.5 )0.5 )[ 85.65 + ( 1.293^2-1 )
  (100-300)]+16^2*300/((32+0.5)0.5)
= 4267.4014 psi
```

Shell Bending Stress due to Joint Interaction [Sigmas,b]:
```
= 6 * ks/ts^2 { betas[ deltas*Ps + as^2*P*s/( Es*ts )] +
  6( 1 - nu*^2)/(E*)( ao/h )^3( 1+h*betas/2 )[ Pe( Zv+Zm*Q1 ) + 2/ao^2*Zm*Q2 ] }
= 6 * 296711/0.5^2 { 0.451 [ 0.15184E-04 * 100 + 16^2
  * 0/(14370000 ) ] +
 6( 1 - 0.31^2 )/(11242843 )( 12.38/2 )^3( 1 + 2 *
 0.451/2 )[ 85.65 ( 0.0762 +0.413 *0.0582 ) +
 2/12.38^2 * 0.413 * -4321 ] }
= -12504.3613 psi
```

Shell Stress Summation vs. Allowable
```
:: | Sigmas,m | + | Sigmas,b | <= 1.5 * Ss
:: | 4267 | + | -12504 | <= 30000 psi
:: 16772, must be <= 30000 psi
```

Computations completed for ASME tubesheet configuration: b

Stress/Force Summary for Loadcase D3 un-corr. (Psd,max + Ptd,max):

Stress Description	Actual		Allowable	Pass/Fail
Tubesheet Bend. Stress	15514.7	<=	30000.0 psi	Ok
Tubesheet Shear Stress	795.0	<=	16000.0 psi	Ok
Maximum Tube Stress	3333.9	<=	11400.0 psi	Ok
Minimum Tube Stress (Buckling)	-3333.9	<=	-9702.1 psi	Ok
Maximum Force on any one Tube	450.0	<=	1077.2 lb.	Ok
Axial Membrane Stress in Shell	4267.4	<=	17000.0 psi	Ok
Shell Stress (jt. inter.)	16771.8	<=	30000.0 psi	Ok

Thickness Results for Loadcase D3 un-corr. (Psd,max + Ptd,max):

Thickness (in.)	Required	Actual	P/F
Tubesheet Thickness :	1.2690	2.0000	Ok

Fixed Tubesheet results per ASME Div. 2 Part 4.18.8 2023

Results for 14 Load Cases:

Case#	--Reqd. Thk. + CA Tbsht	Extnsn	---- Tubesheet Stresses Bend	Allwd	Shear	Allwd	Case Type	Pass/ Fail
D1uc	1.317	1.303	16247	30000	676	16000	Ps+Pt-Th D1	Ok
D2uc	0.150	...	1080	30000	119	16000	Ps+Pt-Th D2	Ok
D3uc	1.269	...	15515	30000	795	16000	Ps+Pt-Th D3	Ok
O1uc	0.820	...	17465	67320	2916	16000	Ps+Pt+Th O1	Ok
O2uc	0.640	...	10471	67320	3313	16000	Ps+Pt+Th O2	Ok
O3uc	0.797	...	16733	67320	3034	16000	Ps+Pt+Th O3	Ok
O4uc	0.662	...	11203	67320	3195	16000	Ps+Pt+Th O4	Ok
D1c	1.482	1.303	18683	30000	831	16000	Ps+Pt-Th-c D1	Ok
D2c	0.275	...	1293	30000	90	16000	Ps+Pt-Th-c D2	Ok
D3c	1.422	...	17607	30000	921	16000	Ps+Pt-Th-c D3	Ok
O1c	0.935	...	18817	67320	2925	16000	Ps+Pt+Th-c O1	Ok
O2c	0.739	...	10411	67320	3249	16000	Ps+Pt+Th-c O2	Ok
O3c	0.905	...	17741	67320	3015	16000	Ps+Pt+Th-c O3	Ok
O4c	0.767	...	11487	67320	3159	16000	Ps+Pt+Th-c O4	Ok
Max:	1.4824	1.303	in.	0.623		0.207	(Str. Ratio)	

Load Case Definitions:

[Ps & Pt]:
Shell-side and Tube-side Design or Operating Pressures
derived from Psd,min Ptd,max, Psox,min, Ptox,max etc. per the
Load Case Tables

[(+-)Th]:
With or Without Thermal Expansion, Tt,mx & Ts,mx

[c]:
With or Without Corrosion Allowance

[D1, D2, D3]:
Design Load Cases using the Maximum and Minimum Design Pressures

[D4]:
Design Load Case using the Minimum (Vacuum) Pressures (if specified)

[O1, O2, O3, O4]:
Operating Load Cases using the Maximum and Minimum Operating Pressures and
Operating Temperatures

Shell Axial Membrane Stress Summary:

Case#	---- Shell Stresses Ten	Allwd	Cmp	Allwd	: ---- Shell Band Stress ---- Ten	Allwd	Cmp	Allwd	: Pass Fail
D1uc	3514	17000	...	...	...	...	...	...	Ok
D2uc	753	17000	...	...	...	...	...	...	Ok
D3uc	4267	17000	...	...	...	...	...	...	Ok
O1uc	5788	69312	...	...	...	...	...	...	Ok
O2uc	3997	69312	...	...	...	...	...	...	Ok
O3uc	6541	69312	...	...	...	...	...	...	Ok
O4uc	3244	69312	...	...	...	...	...	...	Ok
D1c	4127	17000	...	...	...	...	...	...	Ok
D2c	834	17000	...	...	...	...	...	...	Ok
D3c	4961	17000	...	...	...	...	...	...	Ok
O1c	6401	69312	...	...	...	...	...	...	Ok

O2c	4263	69312	...	...	...	...	...	...	Ok
O3c	7235	69312	...	...	...	...	...	...	Ok
O4c	3430	69312	...	...	...	...	...	...	Ok
Max RATIO	0.292		...		...		...		

Tube, Shell and Channel Stress Summary:

	---- Tube Stresses		Tube Loads			Shell Stress	Channel Stress		Pass
Case#	Ten Allwd	Cmp	Allwd	Ld	Allwd	Stress	Allwd	Stress	Allwd	Fail
D1uc	4139 11400	-4139	-9702	559	1077	23227	30000	...	...	Ok
D2uc	881 11400	...	...	119	1077	7962	30000	...	...	Ok
D3uc	3334 11400	-3334	-9702	450	1077	16772	30000	...	...	Ok
O1uc	7397 22800	-7397	-9702	999	2154	19246	69312	...	...	Ok
O2uc	7197 22800	-7197	-9702	972	2154	37486	69312	...	...	Ok
O3uc	7244 22800	-7244	-9702	978	2154	27208	69312	...	...	Ok
O4uc	7351 22800	-7351	-9702	992	2154	29524	69312	...	...	Ok
D1c	4184 11400	-4184	-9702	565	1077	24735	30000	...	...	Ok
D2c	887 11400	...	...	120	1077	8912	30000	...	...	Ok
D3c	3380 11400	-3380	-9702	456	1077	17490	30000	...	...	Ok
O1c	7116 22800	-7116	-9702	961	2154	18638	69312	...	...	Ok
O2c	6924 22800	-6924	-9702	935	2154	37895	69312	...	...	Ok
O3c	6931 22800	-6931	-9702	936	2154	27550	69312	...	...	Ok
O4c	7100 22800	-7100	-9702	958	2154	28983	69312	...	...	Ok
Max RATIO	0.367	0.762		0.524		0.824		...		

Summary of Thickness Comparisons for 14 Load Cases:

Thickness (in.)	Required	Actual	P/F
Tubesheet thickness :	1.4824	2.0000	Ok
Tubesheet thickness flanged extension :	1.3029	2.0000	Ok
Tube thickness :	0.0126	0.0625	Ok

Min Shell length of thk, (.500) adj. to tubesheet: 7.200 in.

Summary of Axial Differential Expansion between Shell and Tubes :

Due to Thermal Expansion	Shell Extends by	: +.0411 in.
Due to Pressure	Shell Extends by	: +.0006 in.
Due to Pressure + Thermal	Shell Extends by	: +.0417 in.

Tubesheet MAWP used to Compute Hydrotest Pressure:

Stress / Force Condition	Tubeside MAWP	0 shellside Stress Rat.	Shellside MAWP	0 tubeside Stress Rat.
Tubesheet Bending Stress	481.72	1.000	2319.96	1.000
Tubesheet Shear Stress	5778.96	1.000	11196.76	1.000
Tube Tensile Stress	817.35	1.000	1285.28	1.000
Tube Compressive Stress	685.14	0.999	No Calc	No Calc
Tube-Tubesheet Joint load	572.14	1.000	899.69	1.000
Shell Stress (Axial, Junction)	481.72	0.573	418.10	1.000
Tube Pressure Stress	2035.70	1.000	1543.96	1.000
Tubesheet Extension Stress	457.91	...	No Calc	No Calc
Minimum MAWP	457.91		418.10	

Tubesheet MAPnc used to Compute Hydrotest Pressure:

Stress / Force	Tubeside	0 shellside	Shellside	0 tubeside

Condition	MAPnc	Stress Rat.	MAPnc	Stress Rat.
Tubesheet Bending Stress	552.07	1.000	2765.50	1.000
Tubesheet Shear Stress	7125.43	1.000	13499.39	1.000
Tube Tensile Stress	824.77	1.000	1292.49	1.000
Tube Compressive Stress	785.77	1.000	No Calc	No Calc
Tube-Tubesheet Joint load	577.34	1.000	904.74	1.000
Shell Stress (Axial, Junction)	577.34	0.584	904.74	0.945
Tube Pressure Stress	2035.70	1.000	1543.96	1.000
Tubesheet Extension Stress	457.91	...	No Calc	No Calc
Minimum MAPnc	457.91		904.74	

(*) All load cases were analyzed to compute the MAWP for determining the test pressure.

Summary of Exchanger Pressure and Thermal Displacements: (in.)

Load	Due to Pressure		Due to Thermal Exp.		Computed Delta Ms	
Case#	UnCorroded	Corroded	UnCorroded	Corroded	UnCorroded	Corroded
1	0.0006	0.0006	...	...	...	...
2	-0.0004	-0.0004	...	...	...	...
3	0.0001	0.0001	...	...	...	...
4	...	...	...	...	...	...
5	0.0006	0.0006	0.0410	0.0411	...	...
6	-0.0004	-0.0004	0.0410	0.0411	...	...
7	0.0001	0.0001	0.0410	0.0411	...	...
8	...	...	0.0410	0.0411	...	...

Tubesheet MDMT Calculations:

Shell Side MDMT calculation:

Governing thickness on the shell side per figure UCS-66.3 (e):
```
  = max( tubesheet thk/4, min( tubesheet thk, shell thickness ) )
  = max( 2/4, min( 2, 0.5 ) )
  = 0.500 in.
```

Thickness Ratio = 0.655, Temperature Reduction per Fig. UCS 66.1 = 34 F

```
Min Metal Temp. w/o impact per UCS-66, Curve B              -6 F
Min Metal Temp. at Required thickness (UCS 66.1)           -41 F
Min Metal Temp. w/o impact per UG-20(f)                    -20 F
```

Channel Side MDMT calculation:

Governing thickness for the channel side:
```
  = tubesheet thickness/4
  = 2/4
  = 0.500 in.
```

Thickness Ratio = 0.655, Temperature Reduction per Fig. UCS 66.1 = 34 F

```
Min Metal Temp. w/o impact per UCS-66, Curve B              -6 F
Min Metal Temp. at Required thickness (UCS 66.1)           -41 F
Min Metal Temp. w/o impact per UG-20(f)                    -20 F
```

where the MDMT reduction ratio per UCS 66 (b)(1)(b) is:
```
  = max( pt/Tubeside MAPnc, ps/Shellside MAPnc ), must be <= 1
  = max( 300/457.9, 100/904.7 )
  = 0.655
```

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