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Layout

Input values:	*1.234*	or	1.234
Calculated values:	***1.234***	or	**1.234**
Critical values:	*1.234*	or	1.234
Estimated values:	*1.234*	or	1.234

Worksheet for pressure vessel design

Drawing No.	Project No.	Sheet	of
Client		DGRL 2014/68/EU (97/23/EG)	
Description			
Project calculated according to		ASME VIII/1	
Material data according to		ASME VIII/1	
Creep range (if applicable)	With lifetime monitoring Design lifetime		No 100000 h

Design data		
Max. allowable working pressure	bar	bar
Test pressure in vertical position	bar	bar
Test pressure in horizontal position	bar	bar
External pressure	bar	bar
Design temperature	°C	°C
Corrosion allowance	mm	in
Joint efficiency		
Volume	l	l

Category
Module

Comments

Loadings acc. UG-22

UG-22(a)	Internal or external design pressure
UG-22(b)	Weight of vessel and normal contents under operating or test conditions
UG-22(c)	Superimposed static reactions from weight of attached equipment (external loads)
UG-22(d)	Attachment of (1) Internals, (2) Supports
UG-22(e)	Cyclic and dynamic reactions due to pressure or thermal variations or mechanical loadings
UG-22(f)	Wind, snow and seismic reactions
UG-22(g)	Impact reactions due to fluid shock
UG-22(h)	Temperature gradients and differential thermal expansion
UG-22(i)	Abnormal pressure
UG-22(j)	Test pressure and coincident static head acting dring the test

Summary

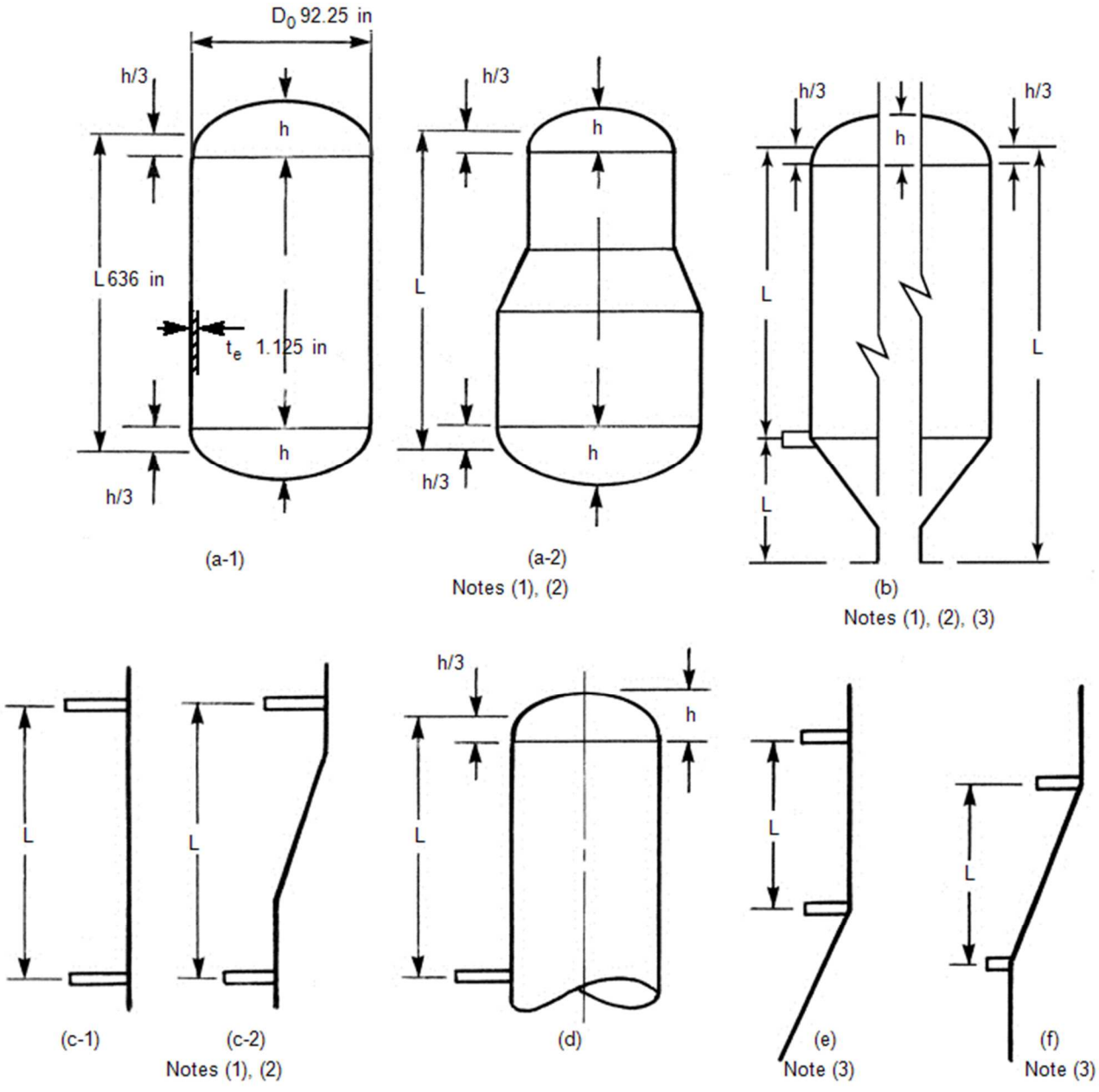
Strength Calculation		
Software	Program System ATLAS	Version **8.29.1**
Developed by Lauterbach Verfahrenstechnik GmbH		
Certified per DIN EN ISO 9001:2015	Certificate Number 01 100 044763	

	LV_Soft		ASME	Diff [%]
Example E4.4.1 - Cylinder Shell under External Pressure Max.allowable Pressure Pa(B)	2,691 bar	39,030 psi	39,000 psi	**0,08%**
Example E4.4.2 - Cylinder Shell under External Pressure Max.allowable Pressure Pa(B)	17,21 bar	249,60 psi	249,60 psi	**0,00%**
Example E4.4.3 - Sperical Shell and Hemispherical Head under External Pressure Max.allowable Pressure Pa(B)	39,39 bar	571,24 psi	571,10 psi	**0,02%**
Example E4.4.4 - torispherical Head under External Pressure Max.allowable Pressure Pa(B)	3,84 bar	55,72 psi	55,80 psi	**0,15%**
Example E4.4.5 - Ellipsoidal Head under External Pressure Max.allowable Pressure Pa(B)	11,46 bar	166,16 psi	166,20 psi	**0,03%**

E4.4.1 - Thickness of cylindrical shells and tubes under external pressure - ASME BPVC VIII-1 UG-28 & Appendix 1: 2017

Cylindrical shells under external pressure

External design pressure	p_D	14.5	psi
Hydrostatic head	D_p	0	psi
External calculation pressure	p_0	**14.5**	psi
Calculation temperature	T_0	300	°F



Outside diameter	D_0	92.25	in
Design wall thickness	t_e	1.125	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Buckling length	L	636	in

Material K02700-SA-516-70-Class:-Size:

Spec. Min. Yield	S_y	33600	psi
Allowable stress	S_0	20015	psi
Applicable material chart	Fig	CS-2	
Modulus of elasticity	E	2.829e+7	psi

Results

Effective thickness	t_0	**1**	in
Ratio	L/D_0	**6.894**	
Ratio	D_0/t_0	**92.25**	
Factor according to ASME-IID\Table G	A	**1.884e-4**	
Factor (see material chart)	B	**2700**	psi
Factor 2*Min(S_0;.9*B)	S	**4860**	psi
Required thickness acc. UG-28	t_{UG-28}	**0.6718**	in
Required thickness acc. UG-16	t_{UG-16}	0.05906	in
Required thickness	t	**0.6718**	in
Required thickness incl. allowances	$t+c_1+c_2$	**0.7968**	in
Allowable excess pressure	P	**38.51**	psi
Allowable pressure without hydrostatic head	MAWP	**38.51**	psi

Remark

Equations

UG-28 c) (1)

$$\frac{D_0}{t_0} \geq 10 \Leftrightarrow 92.25 \geq 10$$

Step 6

$$Pa(B) = \frac{4 \cdot B}{3 \cdot \frac{D_0}{t_0}} = \frac{4 \cdot 18.62\ \text{N/mm}^2}{3 \cdot 92.25} = 0.2691\ \text{MPa}$$

Step 7

$$Pa(E) = \frac{2 \cdot A \cdot E}{3 \cdot \frac{D_0}{t_0}} = \frac{2 \cdot 1.884\text{e-}4 \cdot 195054\ \text{N/mm}^2}{3 \cdot 92.25} = 0.2656\ \text{MPa}$$

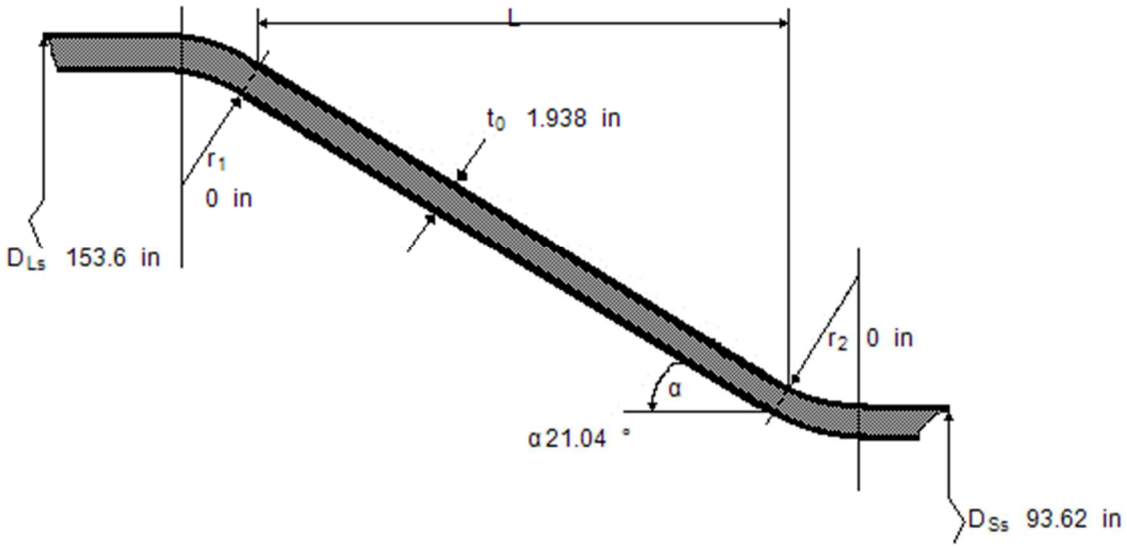
E4.4.2 with B taken by ASME - Formed heads pressure under external pressure - ASME BPVC VIII-1 UG-33 & Appendix-1: 2017

Conical shells under external pressure acc. UG-33(f)

External design pressure	p_D	249	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**249**	psi
Calculation temperature	T_0	300	°F

Material K02700-SA-516-70-Class:-Size:

Spec. Min. Yield	S_y	33600	psi
Allowable stress	S_0	20015	psi
Applicable material chart	Fig	CS-2	
Modulus of elasticity	E	2.9e+7	psi



Cone wall thickness with allowances	t_0	1.938	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Cone wall thickness without allowances	t	**1.813**	in

Is a cylinder connected, which does not act as line of support?		N	(Y/N)
Outside diameter (wide end)	D_{Ls}	153.6	in
Knuckle radius (wide end)	r_1	0	in
Outside diameter (small end)	D_{Ss}	93.62	in
Knuckle radius (small end)	r_2	0	in
Half apex angle (≤ 60°)	α	21.04	°

Proof for cross-section area according to App. 1-8 required for cone-connection without knuckle

Results

Effective thickness	$t_e = t \cdot \cos(\alpha)$	t_e	**1.692**	in
Axial length of the cone		L	**78**	in
Design length		L_e	**62.77**	in
Ratio		L_e/D_L	**0.4086**	
Ratio		D_L/t_e	**90.81**	
Factor according to fig. 5-UGO-28.0		A	**0.004132**	
Factor (see material chart)		B	17000	psi
Factor	$2 \cdot \text{Min}(S_0;.9 \cdot B)$	S	**31589**	psi
Allowable external pressure	(for t0)	P	**249.6**	psi
Allowable pressure without hydrostatic head		MEP	**249.6**	psi
Required thickness	(for P0)	t	**1.819**	in
Required thickness incl. allowances		$t+c_1+c_2$	**1.944**	in

Remark **Thickness not sufficient**

Equations

$cos(\alpha) = cos(\alpha) = cos(21.04°) = 0.9333$

$sin(\alpha) = sin(\alpha) = sin(21.04°) = 0.359$

$tan(\alpha) = tan(\alpha) = tan(21.04°) = 0.3846$

$$D_L = D_{Ls} - r_1 \cdot (1 - \cos(\alpha)) = 3902\text{ mm} - 0\text{ mm} \cdot (1 - 0.9333) = 3902\text{ mm}$$

$$D_S = D_{Ss} + r_2 \cdot (1 - \cos(\alpha)) = 2378\text{ mm} + 0\text{ mm} \cdot (1 - 0.9333) = 2378\text{ mm}$$

$$L = \frac{(D_L - D_S)}{2} \cdot \tan(\alpha) = \frac{(3902\text{ mm} - 2378\text{ mm})}{2} \cdot 0.3846 = 1981\text{ mm}$$

$$L_1 = r_1 \cdot \sin(\alpha) = 0\text{ mm} \cdot 0.359 = 0\text{ mm}$$

$$L_2 = r_2 \cdot \left(\frac{D_{Ss}}{D_{Ls}}\right) \cdot \sin(\alpha) = 0\text{ mm} \cdot 0.6094 \cdot 0.359 = 0\text{ mm}$$

$$L_3 = \frac{L}{2} \cdot \frac{(D_L + D_S)}{D_{Ls}} = \frac{1981\text{ mm}}{2} \cdot \frac{(3902\text{ mm} + 2378\text{ mm})}{3902\text{ mm}} = 1594\text{ mm}$$

$$L_e = L_1 + L_2 + L_3 = 0\text{ mm} + 0\text{ mm} + 1594\text{ mm} = 1594\text{ mm}$$

1) for $D_L/t_0 \geq 10$

UG-33 f-a) Step 6

$$Pa(B) = \frac{4 \cdot B}{3 \cdot \left(\frac{D_L}{t_0}\right)} = \frac{4 \cdot 117.2\text{ N/mm²}}{3 \cdot 90.81} = 1.721\text{ N/mm²}$$

UG-33 f-a) Step 7

$$Pa(E) = \frac{2 \cdot A \cdot E}{3 \cdot \left(\frac{D_L}{t_0}\right)} = \frac{2 \cdot 0.004132 \cdot 199948\text{ N/mm²}}{3 \cdot 90.81} = 6.066\text{ N/mm²}$$

2) for $D_L/t_0 < 10$

UG-33 f-b) Step 2

$$P_{a1}=\left[\frac{2.167}{\frac{D_L}{t_0}}-0.0833\right]\cdot B=\left[\frac{2.167}{90.81}-0.0833\right]\cdot 117.2\ \text{N/mm²}=-6.967\ \text{N/mm²}$$

UG-33 f-b) Step 3

$$P_{a2}=\frac{2\cdot S}{\frac{D_L}{t_0}}\cdot\left[1-\frac{2\cdot S}{\frac{D_L}{t_0}}\right]=\frac{2\cdot 217.8\ \text{N/mm²}}{90.81}\cdot\left[1-\frac{2\cdot 217.8\ \text{N/mm²}}{90.81}\right]=4.744\ \text{N/mm²}$$

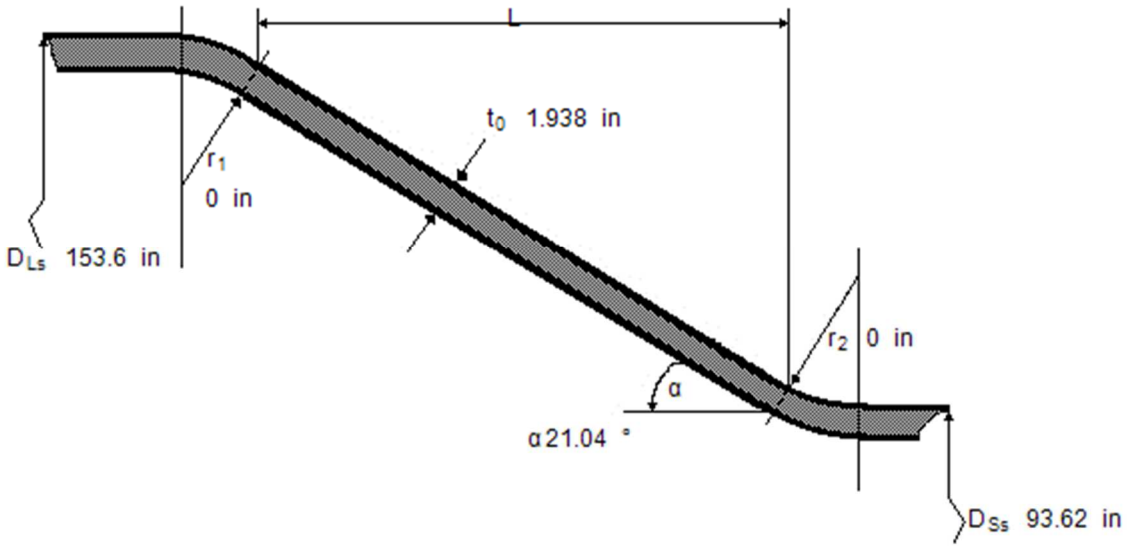
E4.4.2 with B taken by LV - Formed heads pressure under external pressure - ASME BPVC VIII-1 UG-33 & Appendix-1: 2017

Conical shells under external pressure acc. UG-33(f)

External design pressure	p_D	249	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**249**	psi
Calculation temperature	T_0	300	°F

Material K02700-SA-516-70-Class:-Size:

Spec. Min. Yield	S_y	33600	psi
Allowable stress	S_0	20015	psi
Applicable material chart	Fig	CS-2	
Modulus of elasticity	E	2.9e+7	psi



Cone wall thickness with allowances	t_0	1.938	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Cone wall thickness without allowances	t	**1.813**	in

Is a cylinder connected, which does not act as line of support?		N	(Y/N)
Outside diameter (wide end)	D_{Ls}	153.6	in
Knuckle radius (wide end)	r_1	0	in
Outside diameter (small end)	D_{Ss}	93.62	in
Knuckle radius (small end)	r_2	0	in
Half apex angle (≤ 60°)	α	21.04	°

Proof for cross-section area according to App. 1-8 required for cone-connection without knuckle

Results

Effective thickness	$t_e = t \cdot \cos(\alpha)$	t_e	**1.692**	in
Axial length of the cone		L	**78**	in
Design length		L_e	**62.77**	in
Ratio		L_e/D_L	**0.4086**	
Ratio		D_L/t_e	**90.81**	
Factor according to fig. 5-UGO-28.0		A	**0.004132**	
Factor (see material chart)		B	**16887**	psi
Factor	$2 \cdot \text{Min}(S_0;.9 \cdot B)$	S	**31589**	psi
Allowable external pressure	(for t0)	P	**247.9**	psi
Allowable pressure without hydrostatic head		MEP	**247.9**	psi
Required thickness	(for P0)	t	**1.819**	in
Required thickness incl. allowances		$t+c_1+c_2$	**1.944**	in

Remark **Pressure not allowable**

Equations

$cos(\alpha) = cos(\alpha) = cos(21.04°) = 0.9333$

$sin(\alpha) = sin(\alpha) = sin(21.04°) = 0.359$

$tan(\alpha) = tan(\alpha) = tan(21.04°) = 0.3846$

$$D_L = D_{Ls} - r_1 \cdot (1 - \cos(\alpha)) = 3902\text{ mm} - 0\text{ mm} \cdot (1 - 0.9333) = 3902\text{ mm}$$

$$D_S = D_{Ss} + r_2 \cdot (1 - \cos(\alpha)) = 2378\text{ mm} + 0\text{ mm} \cdot (1 - 0.9333) = 2378\text{ mm}$$

$$L = \frac{(D_L - D_S)}{2} \cdot \tan(\alpha) = \frac{(3902\text{ mm} - 2378\text{ mm})}{2} \cdot 0.3846 = 1981\text{ mm}$$

$$L_1 = r_1 \cdot \sin(\alpha) = 0\text{ mm} \cdot 0.359 = 0\text{ mm}$$

$$L_2 = r_2 \cdot \left(\frac{D_{Ss}}{D_{Ls}}\right) \cdot \sin(\alpha) = 0\text{ mm} \cdot 0.6094 \cdot 0.359 = 0\text{ mm}$$

$$L_3 = \frac{L}{2} \cdot \frac{(D_L + D_S)}{D_{Ls}} = \frac{1981\text{ mm}}{2} \cdot \frac{(3902\text{ mm} + 2378\text{ mm})}{3902\text{ mm}} = 1594\text{ mm}$$

$$L_e = L_1 + L_2 + L_3 = 0\text{ mm} + 0\text{ mm} + 1594\text{ mm} = 1594\text{ mm}$$

1) for $D_L/t_0 \geq 10$

UG-33 f-a) Step 6

$$Pa(B) = \frac{4 \cdot B}{3 \cdot \left(\frac{D_L}{t_0}\right)} = \frac{4 \cdot 116.4\text{ N/mm²}}{3 \cdot 90.81} = 1.71\text{ N/mm²}$$

UG-33 f-a) Step 7

$$Pa(E) = \frac{2 \cdot A \cdot E}{3 \cdot \left(\frac{D_L}{t_0}\right)} = \frac{2 \cdot 0.004132 \cdot 199948\text{ N/mm²}}{3 \cdot 90.81} = 6.066\text{ N/mm²}$$

2) for $D_L/t_0 < 10$

UG-33 f-b) Step 2

$$P_{a1}=\left[\frac{2.167}{\frac{D_L}{t_0}}-0.0833\right]\cdot B=\left[\frac{2.167}{90.81}-0.0833\right]\cdot 116.4\ \text{N/mm²}=-6.92\ \text{N/mm²}$$

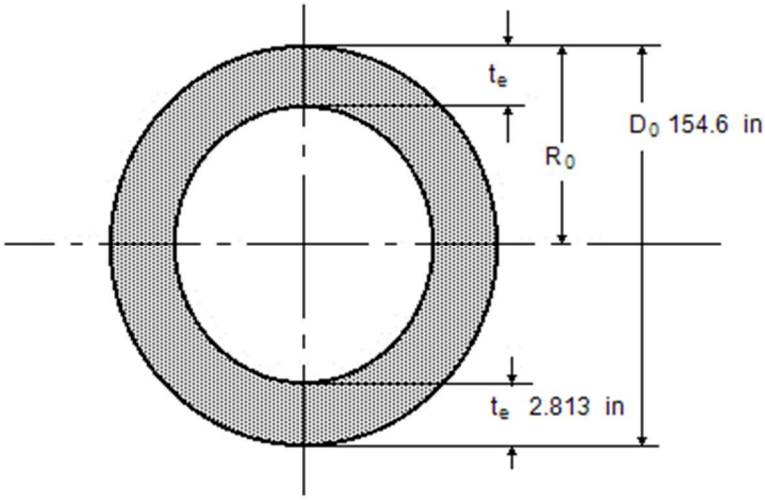
UG-33 f-b) Step 3

$$P_{a2}=\frac{2\cdot S}{\frac{D_L}{t_0}}\cdot\left[1-\frac{2\cdot S}{\frac{D_L}{t_0}}\right]=\frac{2\cdot 217.8\ \text{N/mm²}}{90.81}\cdot\left[1-\frac{2\cdot 217.8\ \text{N/mm²}}{90.81}\right]=4.744\ \text{N/mm²}$$

E4.4.3 with B taken by LV - Thickness of spherical shells under external pressure - ASME BPVC VIII-1 UG-28 & Appendix 1: 2017

Spherical shells under external pressure

External design pressure	p_D	572	psi
Hydrostatic head	D_p	0	psi
External calculation pressure	p_0	**572**	psi
Calculation temperature	T_0	350	°F



Outside diameter	D_0	154.6	in
Design wall thickness	t_e	2.813	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0	in

Material K31835-SA-542-D-Class:4a-Size:

Spec. Min. Yield	S_y	60190	psi
Allowable stress	S_0	24366	psi
Applicable material chart	Fig	CS-2	
Modulus of elasticity	E	2.852e+7	psi

Results

Effective thickness	t_0	**2.813**	in
Tip radius	R_0	**77.3**	in
Ratio	R_0/t_0	**27.48**	
Factor $0.125/(R_0/t_0)$	A	**0.004548**	
Factor (see material chart)	B	**16009**	psi
Required thickness acc. UG-28	t_{UG-28}	**2.767**	in
Required thickness acc. UG-16	t_{UG-16}	0.05906	in
Required thickness	t	**2.767**	in
Required thickness incl. allowances	$t+c_1+c_2$	**2.767**	in
Allowable excess pressure	P	**582.5**	psi
Allowable pressure without hydrostatic head	MAWP	**582.5**	psi

Remark

Equations

UG-28 d) Step 4

$$Pa(B) = \frac{B}{\left(\frac{R_0}{t_0}\right)} = \frac{110.4\ \text{N/mm}^2}{27.48} = 4.016\ \text{MPa}$$

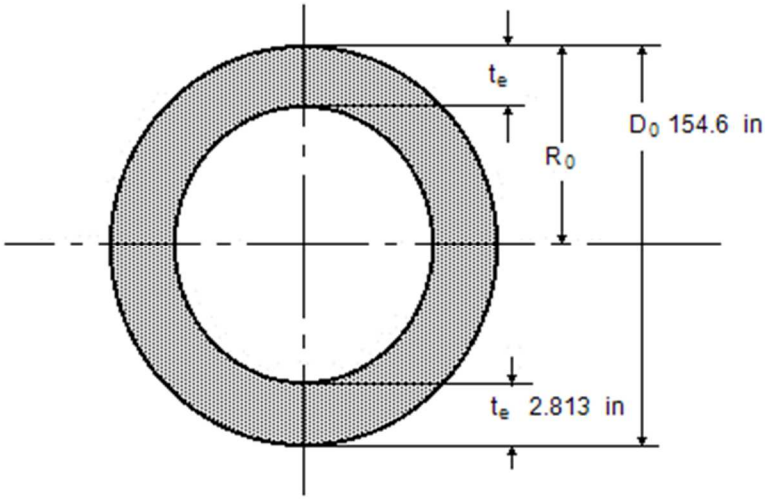
UG-28 d) Step 5

$$Pa(E) = 0.0625 \cdot \frac{E}{\left(\frac{R_0}{t_0}\right)^2} = 0.0625 \cdot \frac{196606\ \text{N/mm}^2}{(27.48)^2} = 16.27\ \text{MPa}$$

E4.4.3 with B taken by ASME - Thickness of spherical shells under external pressure - ASME BPVC VIII-1 UG-28 & Appendix 1: 2017

Spherical shells under external pressure

External design pressure	p_D	571.1	psi
Hydrostatic head	D_p	0	psi
External calculation pressure	p_0	**571.1**	psi
Calculation temperature	T_0	350	°F



Outside diameter	D_0	154.6	in
Design wall thickness	t_e	2.813	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0	in

Material K31835-SA-542-D-Class:4a-Size:

Spec. Min. Yield	S_y	60190	psi
Allowable stress	S_0	24366	psi
Applicable material chart	Fig	CS-2	
Modulus of elasticity	E	2.852e+7	psi

Results

Effective thickness	t_0	**2.813**	in
Tip radius	R_0	**77.3**	in
Ratio	R_0/t_0	**27.48**	
Factor $0.125/(R_0/t_0)$	A	**0.004548**	
Factor (see material chart)	B	15700	psi
Required thickness acc. UG-28	t_{UG-28}	**2.763**	in
Required thickness acc. UG-16	t_{UG-16}	0.05906	in
Required thickness	t	**2.763**	in
Required thickness incl. allowances	$t+c_1+c_2$	**2.763**	in
Allowable excess pressure	P	**571.2**	psi
Allowable pressure without hydrostatic head	MAWP	**571.2**	psi

Remark

Equations

UG-28 d) Step 4

$$Pa(B) = \frac{B}{\left(\frac{R_0}{t_0}\right)} = \frac{108.2\ \text{N/mm}^2}{27.48} = 3.939\ \text{MPa}$$

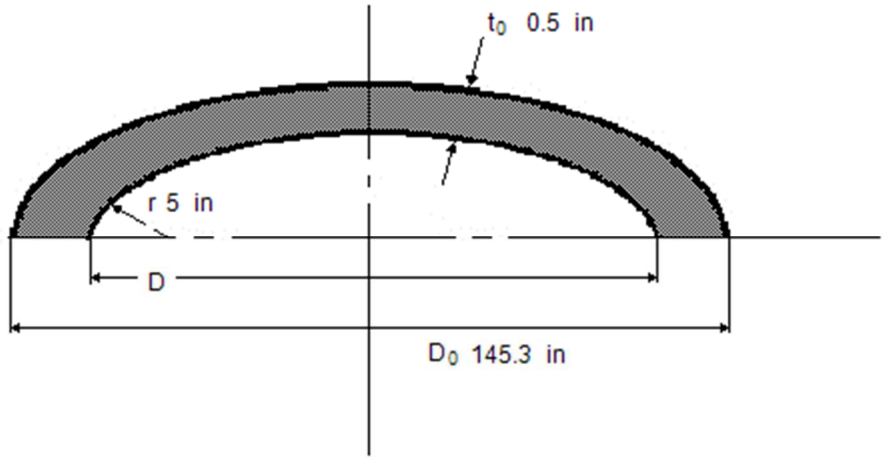
UG-28 d) Step 5

$$Pa(E) = 0.0625 \cdot \frac{E}{\left(\frac{R_0}{t_0}\right)^2} = 0.0625 \cdot \frac{196606\ \text{N/mm}^2}{(27.48)^2} = 16.27\ \text{MPa}$$

E4.4.4 with B taken by LV - Formed heads pressure under external pressure - ASME BPVC VIII-1 UG-33 & Appendix-1: 2017

Torispherical heads

External design pressure	p_D	55.6	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**55.6**	psi
Calculation temperature	T_0	650	°F
Design wall thickness	t_e	0.625	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Effective thickness	t_0	**0.5**	in



Outside diameter of the head skirt	D_0	145.3	in
Type of head Torispherical head			
Outside calotte radius	R_0	72.63	in
Knuckle radius	r	5	in
Material K11789-SA-387-11-Class:1-Size:			
Spec. Min. Yield	S_y	34809	psi
Allowable stress	S_0	17114	psi
Applicable material chart	Fig	CS-2	
Modulus of elasticity	E	2.512e+7	psi

Results

Ratio	R_0/t_0	**145.3**	
Factor (see material chart)	B	**8093**	psi
Allowable external pressure	P	**55.72**	psi
Allowable pressure without hydrostatic head	MEP	**55.72**	psi
Required thickness	t	0.499	in
Required thickness incl. allowances	$t+c_1+c_2$	0.624	in

Remark

Equations

UG-28 d) Step 4

$$Pa(B) = \frac{B}{\left(R_0 / t_0 \right)} = \frac{55.8\ \text{N/mm}^2}{145.3} = 0.3842\ \text{N/mm}^2$$

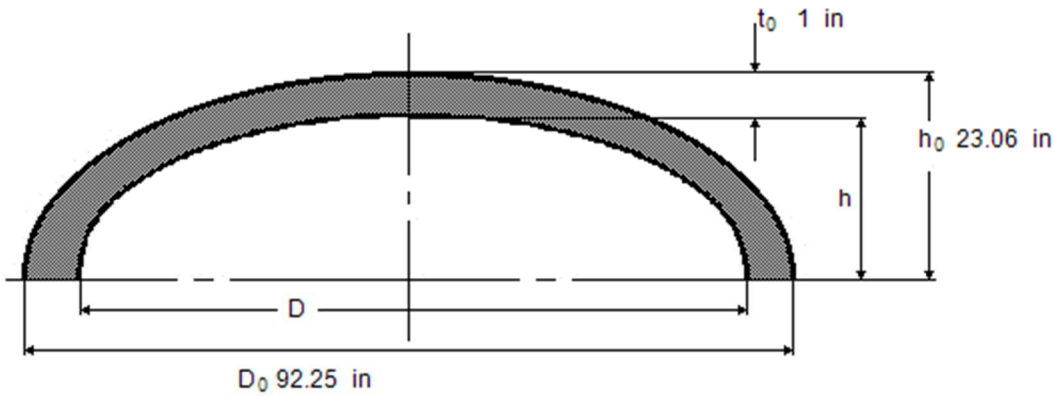
UG-28 d) Step 5

$$Pa(E) = 0.0625 \cdot \frac{E}{\left(R_0 / t_0 \right)^2} = 0.0625 \cdot \frac{173231\ \text{N/mm}^2}{(145.3)^2} = 0.5131\ \text{N/mm}^2$$

E4.4.5 - Formed heads pressure under external pressure - ASME BPVC VIII-1 UG-33 & Appendix-1: 2017

Ellipsoidal heads under external pressure

External design pressure	p_D	166.1	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**166.1**	psi
Calculation temperature	T_0	300	°F
Final wall thickness	t_e	1.125	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Effective thickness	t_0	**1**	in



Outside diameter of the head skirt	D_0	92.25	in
Outer height of crown (short semiaxis)	h_0	23.06	in
Material	K02700-SA-516-70-Class:-Size:		
Spec. Min. Yield	S_y	37710	psi
Allowable stress	S_0	20015	psi
Applicable material chart	Fig	CS-2	
Modulus of elasticity	E	2.9e+7	psi

Results

Ratio		$D_0/2h_0$	**2**	
Factor (according to chart UG-33.1)		K_0	**0.9**	
Design radius of crown	(= $K_0 \cdot D_0$)	R_0	**83.02**	in
Ratio		R_0/t_0	**83.02**	
Factor	$0.125/(R_0/t_0)$	A	**0.001506**	
Factor (see material chart)		B	**13795**	psi
Allowable external pressure		P	**166.2**	psi
Allowable pressure without hydrostatic head		MEP	**166.2**	psi
Required thickness without allowance		t	0.9999	in
Required thickness incl. allowances		$t+c_1+c_2$	1.125	in

Remark

Equations

UG-28 d) Step 4

$$Pa(B) = \frac{B}{\left(R_0 / t_0 \right)} = \frac{95.11\ \text{N/mm}^2}{83.02} = 1.146\ \text{N/mm}^2$$

UG-28 d) Step 5

$$Pa(E) = 0.0625 \cdot \frac{E}{\left(R_0 / t_0 \right)^2} = 0.0625 \cdot \frac{199948\ \text{N/mm}^2}{(83.02)^2} = 1.813\ \text{N/mm}^2$$

Appendix: Material documentation

Section 2: Schale/E4.4.1
Section 3: Boden/E4.4.2 with B taken by ASME
Section 4: Boden/E4.4.2 with B taken by LV
Section 8: Boden/E4.4.5

Material specification:

Regulation: ASMET1A:2017Spec. No.: SA-516 Product: Plate
Material code: K02700-SA-516-70-Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 148,8889 Pressure [bar]: 1
Thickness [mm]: 28,575 Outside diameter [mm]: 2343,15

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138.00	138.00
Safety factor:		
Allowable stress [N/mm²]:	138.00	138.00
Modulus of elasticity [kN/mm²]:	202,35	195,0667

Wall thickness tolerance [mm]: 0.00 acc. to SA-516
Notes:
G10 General Requirements
Upon prolonged exposure to temperatures above 425°C, the carbide phase of carbon steel may be converted to graphite. See Nonmandatory Appendix A, A–201 and A–202.

S1 Size Requirements
For Section I applications, stress values at temperatures of 450°C and above are permissible but, except for tubular products 75 mm O.D. or less enclosed within the boiler setting, use of these materials at these temperatures is not current practice.

T2 Time-Dependent Properties
Allowable stresses for temperatures of 400°C and above are values obtained from time–dependent properties.

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Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. lngt. %	Rupture elong. lat. %

K-values as function of the temperature

Diam./Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		138	138	138	138	136	128	101

K-values as function of the temperature

Diam./Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
	67.1	33.6	12.9				

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550

209	216	212	202	198	195	192	189	185	179	171	162	151	137

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7.85	12,1	12,7	13,3	13,8	14,4	14.8	15.1	15.4		

Section 5: Schale/E4.4.3 with B taken by LV
Section 6: Schale/E4.4.3 with B taken by ASME

Material specification:

Regulation:	ASMET1A:2017	Spec. No.: SA-542	Product: Plate
Material code:	K31835-SA-542-D-Class:4a-Size:		Short name: 2.25Cr-1Mo-V

Design conditions and dimensions:

Temperature [°C]:	176,6667	Pressure [bar]:	39,43826
Thickness [mm]:	71,4375	Outside diameter [mm]:	3926,84

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	168.00	168.00
Safety factor:		
Allowable stress [N/mm²]:	168.00	168.00
Modulus of elasticity [kN/mm²]:	200	196,606

Wall thickness tolerance [mm]: 0.00 acc. to SA-542
Notes:

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Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. lngt. %	Rupture elong. lat. %

K-values as function of the temperature

Diam./Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
	168	168	168	168	165	159	153	

K-values as function of the temperature

Diam./Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
	145	137					

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

260	370	480	425	20	150
186	169	143	157	200	200

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
·····	12,1	12,7	13,3	13,8	14,4	14.8	15.1	15.4	·····	·····

Section 7: Boden/E4.4.4 with B taken by LV

Material specification:

Regulation: ASMET1A:2017Spec. No.: SA-387 Product: Plate
Material code: K11789-SA-387-11-Class:1-Size: Short name: 1.25Cr-0.5Mo-Si

Design conditions and dimensions:

Temperature [°C]: 343,3333 Pressure [bar]: 3,833509
Thickness [mm]: 15,875 Outside diameter [mm]: 3690,62

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	118.00	118.00
Safety factor:		
Allowable stress [N/mm²]:	118.00	118.00
Modulus of elasticity [kN/mm²]:	204,3	183,4

Wall thickness tolerance [mm]: 0.00 acc. to SA-387
Notes:
S4 Size Requirements
For Section I applications, stress values at temperatures of 625°C and above are permissible but, except for tubular products 75 mm O.D. or less enclosed within the boiler setting, use of these materials at these temperatures is not current practice.

T4 Time-Dependent Properties
Allowable stresses for temperatures of 480°C and above are values obtained from time–dependent properties.

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Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. lngt. %	Rupture elong. lat. %
·····	·····	·····	·····	·····	·····

K-values as function of the temperature

Diam./Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
·····	·····	118	118	118	118	118	118	118

K-values as function of the temperature

Diam./Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
·····	114	74.7	36.5	17.6	8.08	·····	·····

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

650	-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550

150	210	218	213	204	200	197	193	190	186	183	179	174	169	164

Static modulus of elasticity in [kN/mm²] at the temperature of

600	700				
157	142				

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7.85	12,1	12,7	13,3	13,8	14,4	14.8	15.1	15.4		