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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

Comparison - Form for equations

Equation form

Comment
Results for example E4.3.7-8 acc. ASME and Lauterbach Verfahrenstechnik GmbH (LV)
The LV-program uses formulas for thick cylinders acc. ASME VIII UG33 and App.1.

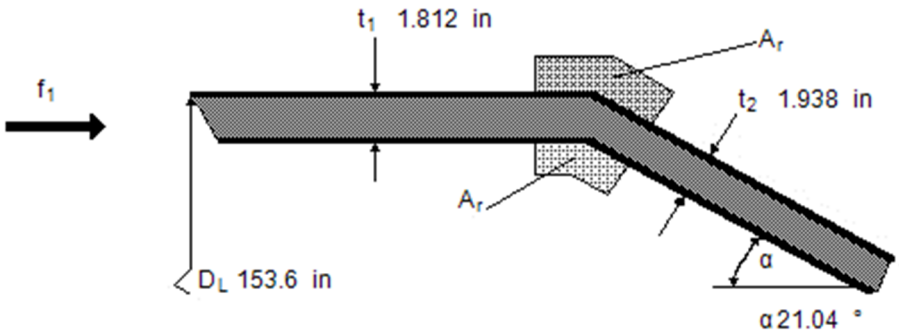
Equations		Value
Conversion factor	mm2in = 0.03937	0.03937
.	mm^2toin^2=0.00155	0.00155
.	mm^4toin^4=0.0000024027	2.403e-6
'Results Ex. E4.4.7 Large End LV and ASME		0
Del acc.to LV = #85(5)		1.836
Del acc. to Asme = 1.75		1.75
Required area acc. LV	ArL = 0.00155*#103(5)	1.565
Required area ASME	ArLAsme = 1.5622	1.562
Difference in %	Diff1 = (ArL-ArLAsme)/ArLAsme*100	0.174
Required area acc. LV	AeL = 0.00155*#105(5)	32.14
Required area ASME	AeLAsme = 32.1407	32.14
Difference in %	Diff2 = (AeL-AeLAsme)/AeLAsme*100	-2.8e-4
Required moment of inertia acc.LV	IsL= 0.000002407*#76(4)	81.53
Required moment of inertia acc.LV	IsAsme= 81.845	81.85
Difference in %	Diff3 = (81.53-81.845)/81.845*100	-0.3849
'Results Ex. E4.4.7 Small End LV and ASME		0
Required area acc. LV	ArS = 0.00155*#104(2)	1.11
Required area ASME	ArSAsme = 1.1106	1.111
Difference in %	Diff4 = (ArS-ArSAsme)/ArSAsme*100	-0.07735
Required area acc. LV	Aes = 0.00155*#106(2)	9.936
Required area ASME	AesAsme = 10.1129	10.11
Difference in %	Diff5 = (Aes-AesAsme)/AesAsme*100	-1.753
Required moment of inertia acc.LV	IsS= 0.000002407*#76(7)	16.79
Required moment of inertia acc.LV	IsAsme= 16.7632	16.76
Difference in %	Diff6 = (16.79-16.7632)/16.7632*100	0.1599
'Results Ex. E4.4.8 Large End LV and ASME		0
Required moment of inertia acc.LV	Is= 0.000002407*#76(10)	14.09
Required moment of inertia acc.LV	IsAsme= 13.8199	13.82
Difference in %	Diff7 = (Is-IsAsme)/IsAsme*100	1.969
Required moment of inertia acc.LV	I´s= 0.000002407*#77(10)	18.1
Required moment of inertia acc.LV	I´sAsme= 17.7504	17.75
Difference in %	Diff7 = (I´s-I´sAsme)/I´sAsme*100	1.969
'Maximum difference between LV and ASME		0
Dmax = Max(|Diff1|;|Diff2|;|Diff3|;|Diff4|;|Diff5|,|Diff6|;|Diff7|)		1.969

E4.4.7 Large End - Formed heads pressure on convex side ASME BPVC VIII UG-33 and APP. 1, 2017 Edition

Area at the wide end of a cone-cylinder-juncture without knuckle acc. App.1-8

Type of stiffener No stiffener

External design pressure	p_D	14.7	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**14.7**	psi
Calculation temperature	T_0	300	°F
Axial load (for positive tension)	f_1	497.1	lbf/in



Cylinder

Final wall thickness	t_1	1.812	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Final thickness without allowances	t_s	**1.687**	in
Outside diameter	D_L	153.6	in
Tip radius (=D_L/2)	R_L	**76.81**	in
Required thickness without allowances (UG-28)	t_{1r}	0.9549	in
Required thickness with allowances (UG-28)	t_{1r+}	**1.08**	in
Joint efficiency factor	E_1	1	
Material K02700-SA-516-70-Class:-Size:			
Allowable stress	S_s	20015	psi
Modulus of elasticity	E_s	2.9e+7	psi

Cone

Final wall thickness	t_2	1.938	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	**0.125**	in
Final thickness without allowances	t_c	**1.813**	in
Half apex angle (≤ 60°)	α	21.04	°
Required thickness without allowances (UG-33)	t_{2r}	*0.3639*	in
Required thickness with allowances (UG-33)	t_{2r+}	*0.4889*	in
Joint efficiency factor	E_2	1	
Material K02700-SA-516-70-Class:-Size:			
Allowable stress	S_c	20015	psi
Modulus of elasticity	E_c	2.9e+7	psi

Stiffening ring

Material K02700-SA-516-70-Class:-Size:			
Actual cross section of the stiffener	A_r	34	in²
Allowable stress	S_r	20015	psi
Modulus of elasticity	E_r	2.9e+7	psi

Results

Factor (≥ 1)	k	**1**	
Ratio	P_0/S_sE_1	**7.344e-4**	
Angle	D_{el}	**1.836**	°
Effective load	Q_L	**1062**	lbf/in
Cross sectional area	A_{rL}	**1.565**	in²
Effective area	A_{eL}	**32.14**	in²
Required cross section of reinforcement	A_{req}	**0**	in²

Remark **Stiffening required acc. App. 1-8 (b)**

Equations

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

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

$$Q_L=P_0\cdot\frac{R_L}{2}+f_1=1.014\text{ bar}\cdot\frac{1951\text{ mm}}{2}+87.06\text{ N/mm}=185.9\text{ N/mm}$$

$$A_{rL}=\frac{k\cdot Q_L\cdot R_L\cdot\tan(\alpha)}{S_s\cdot E_1}\cdot\left(1-\frac{P_0\cdot R_L-Q_L}{4\cdot Q_L}\cdot\frac{D_{el}}{\alpha}\right)=$$

$$\frac{1\cdot 185.9\text{ N/mm}\cdot 1951\text{ mm}\cdot 0.3846}{138\text{ N/mm}^2\cdot 1}\cdot\left(1-\frac{1.014\text{ bar}\cdot 1951\text{ mm}-185.9\text{ N/mm}}{4\cdot 185.9\text{ N/mm}}\cdot\frac{1.836°}{21.04°}\right)=1010\text{ mm}^2 \quad (1)$$

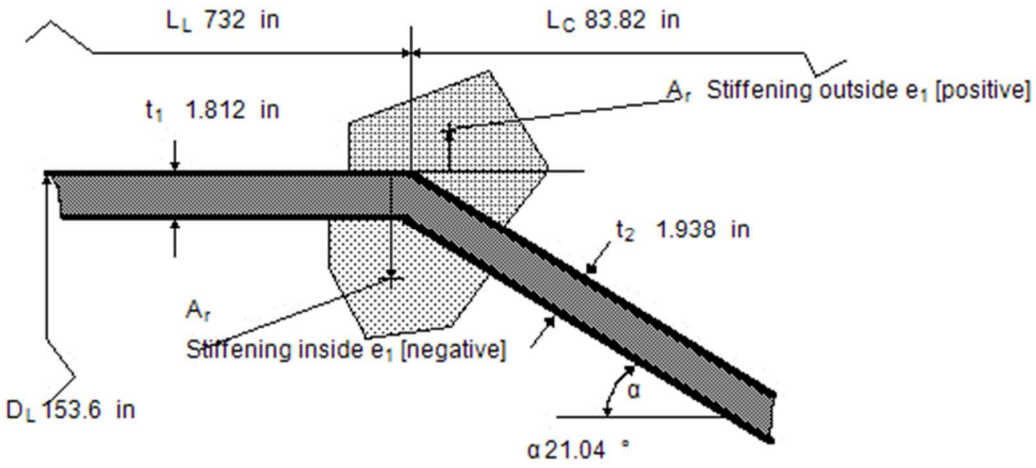
$$A_{eL}=0.55\cdot\sqrt{(D_L\cdot t_s)}\cdot\left(\frac{t_s+t_c}{\cos(\alpha)}\right)=$$

$$0.55\cdot\sqrt{(3902\text{ mm}\cdot 42.86\text{ mm})}\cdot\left(\frac{42.86\text{ mm}+46.04\text{ mm}}{0.9333}\right)=20736\text{ mm}^2 \quad (2)$$

E4.4.7 Large End/Line-of-support - Formed heads pressure on convex side ASME BPVC VIII UG-33 and APP. 1, 2017 Edition

Moment of inertia at the wide end of a cone-cylinder-juncture under external pressure acc. App. 1-8 (Line-of-support)

External design pressure	p_D	14.7	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**14.7**	psi
Calculation temperature	T_0	300	°F
Axial load (for positive tension)	f_1	497.1	lbf/in



Cylinder

Design wall thickness	t_1	1.812	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Final thickness without allowances	t_s	**1.687**	in
Required thickness without allowances (UG-28)	t_{1r}	0.9549	in
Required thickness with allowances (UG-28)	t_{1r+}	**1.08**	in
Outside diameter	D_L	153.6	in
Tip radius (=D_L/2)	R_L	**76.81**	in
Buckling length	L_L	732	in

Cone

Design wall thickness	t_2	1.938	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	**0.125**	in
Final thickness without allowances	t_c	**1.813**	in
Required thickness without allowances (UG-33)	t_{2r}	0.3639	in
Required thickness with allowances (UG-33)	t_{2r+}	0.4889	in
Half apex angle (≤ 60°)	α	21.04	°
Buckling length	L_C	83.82	in

Stiffening ring

Material	K02700-SA-516-70-Class:-Size:		
Spec. Min. Yield	S_y	2.9e+7	psi
Applicable material chart	Fig	CS-2	
Centroidal distance	e_1		in
Cross sectional area	A_r	0	in²
Moment of inertia	I_r		in^4

Results

Equivalent length	M	**393.8**	in
Effective load	F_L	**5980**	lbf/in
Reference area	A_{TL}	**693.6**	in²
Factor	B	**993.4**	psi
Factor (see material chart)	A	**6.96e-5**	
Required moment of inertia	I_s	**81.38**	in^4
Required moment of inertia	I'_s	**104.5**	in^4
Length of support	$0.55\cdot\sqrt{(D\cdot t_s)}$	**8.856**	in
Available moment of inertia	I'		in^4
Remark			

Equations

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

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

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

$R_S=R_L-L_C\cdot\sin(\alpha)=1951\text{ mm}-2129\text{ mm}\cdot 0.359=1172\text{ mm}$

$$M=\frac{-R_L\cdot\tan(\alpha)}{2}+\frac{L_L}{2}+\frac{RL^2-RS^2}{3\cdot R_L\cdot\tan(\alpha)}=$$

$$\frac{-1951\text{ mm}\cdot 0.3846}{2}+\frac{18593\text{ mm}}{2}+\frac{(1951\text{ mm})^2-(1172\text{ mm})^2}{3\cdot 1951\text{ mm}\cdot 0.3846}=10002\text{ mm}$$

App. 1-8 b-3) Step 1

$$F_L=P_0\cdot M+f_1\cdot\tan(\alpha)=$$

$1.014\text{ bar}\cdot 10002\text{ mm}+87.06\text{ N/mm}\cdot 0.3846=1047\text{ N/mm}$

App. 1-8 b-3) Step 1

$$A_{TL}=L_L\cdot\frac{t_s}{2}+L_C\cdot\frac{t_c}{2}+A_s=$$

$$18593\text{ mm}\cdot\frac{42.86\text{ mm}}{2}+2129\text{ mm}\cdot\frac{46.04\text{ mm}}{2}+0\text{ mm²}=447474\text{ mm²}$$

App. 1-8 a)

$$B=\frac{3}{4}\cdot\frac{F_L\cdot D_L}{A_{TL}}=\frac{3}{4}\cdot\frac{1047\text{ N/mm}\cdot 3902\text{ mm}}{447474\text{ mm²}}=6.849\text{ N/mm²}$$

App. 1-8 b-3) Step 1

$$I_s=A\cdot D_L^2\cdot\frac{A_{TL}}{14}=6.96e\text{-}5\cdot(3902\text{ mm})^2\cdot\frac{447474\text{ mm²}}{14}=3.387e+7\text{ mm^4}$$

App. 1-8 b-3) Step 6

$$I'_s=A\cdot D_L^2\cdot\frac{A_{TL}}{10.9}=6.96e\text{-}5\cdot(3902\text{ mm})^2\cdot\frac{447474\text{ mm²}}{10.9}=4.35e+7\text{ mm^4}$$

App. 1-8 b-3) Step 6

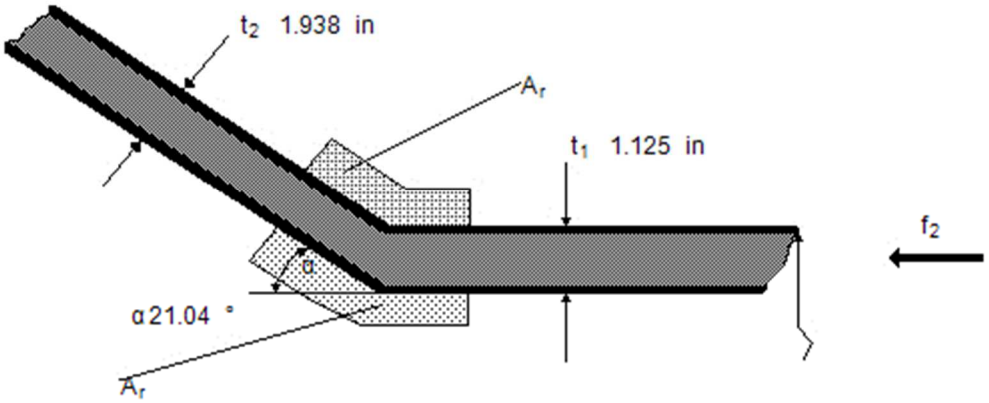
$$0.55\cdot\sqrt{(D\cdot t_s)}=0.55\cdot\sqrt{(3902\text{ mm}\cdot 42.86\text{ mm})}=224.9\text{ mm}$$

E4.4.7 Small End - Formed heads pressure on convex side ASME BPVC VIII UG-33 and APP. 1, 2017 Edition

Area at the small end of a cone-cylinder-juncture without knuckle

Type of stiffener: No stiffener

External design pressure	p_D	14.7	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**14.7**	psi
Calculation temperature	T_0	300	°F
Axial load (for positive tension)	f_2	913	lbf/in



Cylinder

Final wall thickness	t_1	1.125	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Final thickness without allowances	t_s	**1**	in
Outside diameter	D_S	92.25	in
Tip radius (=D_S/2)	R_S	**46.12**	in
Required thickness without allowances (UG-28)	t_{1r}	0.6718	in
Required thickness with allowances (UG-28)	t_{1r+}	**0.7968**	in
Joint efficiency factor	E_1	1	
Material K02700-SA-516-70-Class:-Size:			
Allowable stress	S_s	20015	psi
Modulus of elasticity	E_s	2.9e+7	psi

Cone

Final wall thickness	t_2	1.938	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Final thickness without allowances	t_c	**1.813**	in
Semi aperture angle (≤ 60°)	α	21.04	°
Required thickness without allowances (UG-33)	t_{2r}	*0.3639*	in
Required thickness with allowances (UG-33)	t_{2r+}	**0.4889**	in
Joint efficiency factor	E_2	1	
Material K02700-SA-516-70-Class:-Size:			
Allowable stress	S_c	20015	psi
Modulus of elasticity	E_c	2.9e+7	psi

Stiffening ring

Material			
Actual cross section of the stiffener	A_r		in²
Allowable stress	S_r		psi
Modulus of elasticity	E_r		psi

Results

Factor	k	**1**	≥ 1
Effective load	Q_S	**1252**	lbf/in
Cross sectional area	A_{rS}	**1.11**	in²
Effective area	A_{eS}	**9.936**	in²
Required cross section of the stiffener	A_{req}	**0**	in²
Remark			

Equations

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

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

$$Q_S=P_0\cdot\frac{R_S}{2}+f_2=1.014\text{ bar}\cdot\frac{1172\text{ mm}}{2}+159.9\text{ N/mm}=219.3\text{ N/mm}$$

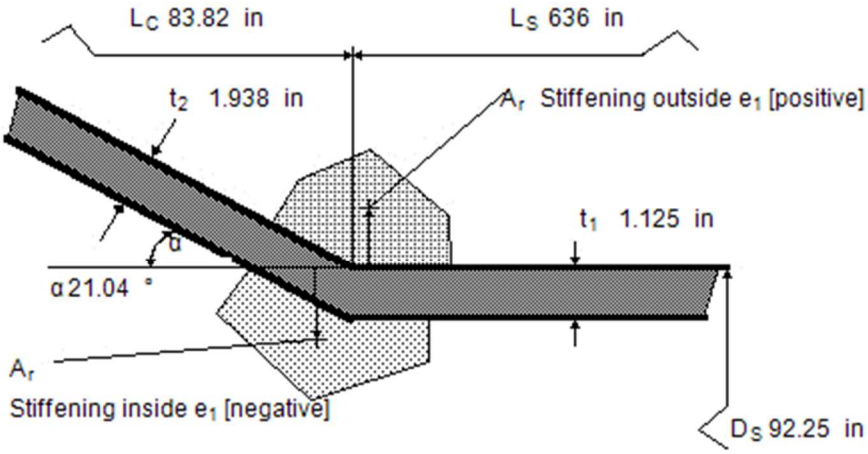
$$A_{rS}=\frac{k\cdot Q_S\cdot R_S\cdot\tan(\alpha)}{S_s\cdot E_1}=\frac{1\cdot 219.3\text{ N/mm}\cdot 1172\text{ mm}\cdot 0.3846}{138\text{ N/mm}^2\cdot 1}=716\text{ mm}^2 \quad (3)$$

$$A_{eS}=0.55\cdot\sqrt{D_S\cdot t_s}\cdot\left[\frac{t_s-t+(t_c-t_r)}{\cos(\alpha)}\right]=$$
$$0.55\cdot\sqrt{2343\text{ mm}\cdot 25.4\text{ mm}}\cdot\left[\frac{25.4\text{ mm}-17.06\text{ mm}+(46.05\text{ mm}-9.242\text{ mm})}{0.9333}\right]=6410\text{ mm}^2 \quad (4)$$

E4.4.7 Small End/Line-of-support - Formed heads pressure on convex side ASME BPVC VIII UG-33 and APP. 1, 2017 Edition

Moment of inertia at the small end of a cone-cylinder-juncture under external pressure acc. App.1-8 (Line-of-support)

External design pressure	p_D	14.7	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**14.7**	psi
Calculation temperature	T_0	300	°F
Axial load (for positive tension)	f_2	913	lbf/in



Cylinder

Final wall thickness	t_1	1.125	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Final thickness without allowances	t_s	**1**	in
Required thickness without allowances (UG-28)	t_{1r}	0.6718	in
Required thickness with allowances (UG-28)	t_{1r+}	**0.7968**	in
Outside diameter	D_S	92.25	in
Tip radius (=D_S/2)	R_S	**46.12**	in
Buckling length	L_S	636	in

Cone

Final wall thickness	t_2	1.938	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Final thickness without allowances	t_c	**1.813**	in
Required thickness without allowances (UG-33)	t_{2r}	0.3639	in
Required thickness with allowances (UG-33)	t_{2r+}	**0.4889**	in
Semi-apex angle (≤ 60°)	α	21.04	°
Buckling length	L_C	83.82	in

Stiffening ring

Material	K02700-SA-516-70-Class:-Size:		
Spec. Min. Yield	S_y	2.9e+7	psi
Applicable material chart	Fig	CS-2	
Centroidal distance	er		in
Cross sectional area	A_r	0	in²
Moment of inertia	I_r		in^4

Results

Equivalent length	N	**362.3**	in
Effective load	F_S	**5677**	lbf/in
Reference area	A_{TS}	**394**	in²
Factor	B	**997**	psi
Factor (see material chart)	A	**6.998e-5**	
Required moment of inertia	I_s	**16.76**	in^4
Required moment of inertia	I'_s	**21.53**	in^4
Length of support	$0.55\cdot\sqrt{(D\cdot t_s)}$	**5.283**	in
Available moment of inertia	I'		in^4
Remark			

Equations

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

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

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

$R_S=R_L-L_C\cdot\sin(\alpha)=1952\text{ mm}-2129\text{ mm}\cdot 0.359=1172\text{ mm}$

$$N=\frac{R_S\cdot\tan(\alpha)}{2}+\frac{L_S}{2}+\frac{RL^2-RS^2}{6\cdot R_S\cdot\tan(\alpha)}=$$

$$\frac{1172\text{ mm}\cdot 0.3846}{2}+\frac{16154\text{ mm}}{2}+\frac{(1952\text{ mm})^2-(1172\text{ mm})^2}{6\cdot 1172\text{ mm}\cdot 0.3846}=9203\text{ mm}$$

$994.3\text{ N/mm}=1.014\text{ bar}\cdot 9203\text{ mm}+159.9\text{ N/mm}\cdot 0.3846$

$$A_{TS}=L_S\cdot\frac{t_s}{2}+L_C\cdot\frac{t_c}{2}+A_S=16154\text{ mm}\cdot\frac{25.4\text{ mm}}{2}+2129\text{ mm}\cdot\frac{46.05\text{ mm}}{2}+0\text{ mm²}=254182\text{ mm²}$$

$$B=\frac{3}{4}\cdot\frac{F_S\cdot D_S}{AT_S}=\frac{3}{4}\cdot\frac{994.3\text{ N/mm}\cdot 2343\text{ mm}}{254182\text{ mm²}}=6.874\text{ N/mm²}$$

$$I_s=\frac{A\cdot DS^2\cdot A_{TS}}{14}=\frac{6.998\text{e-}5\cdot(2343\text{ mm})^2\cdot 254182\text{ mm²}}{14}=6975754\text{ mm^4}$$

$$I'_s=\frac{A\cdot DS^2\cdot A_{TS}}{10.9}=\frac{6.998\text{e-}5\cdot(2343\text{ mm})^2\cdot 254182\text{ mm²}}{10.9}=8959684\text{ mm^4}$$

$$0.55\cdot\sqrt{(D\cdot t_s)}=0.55\cdot\sqrt{(D\cdot 25.4\text{ mm})}=134.2\text{ mm}$$

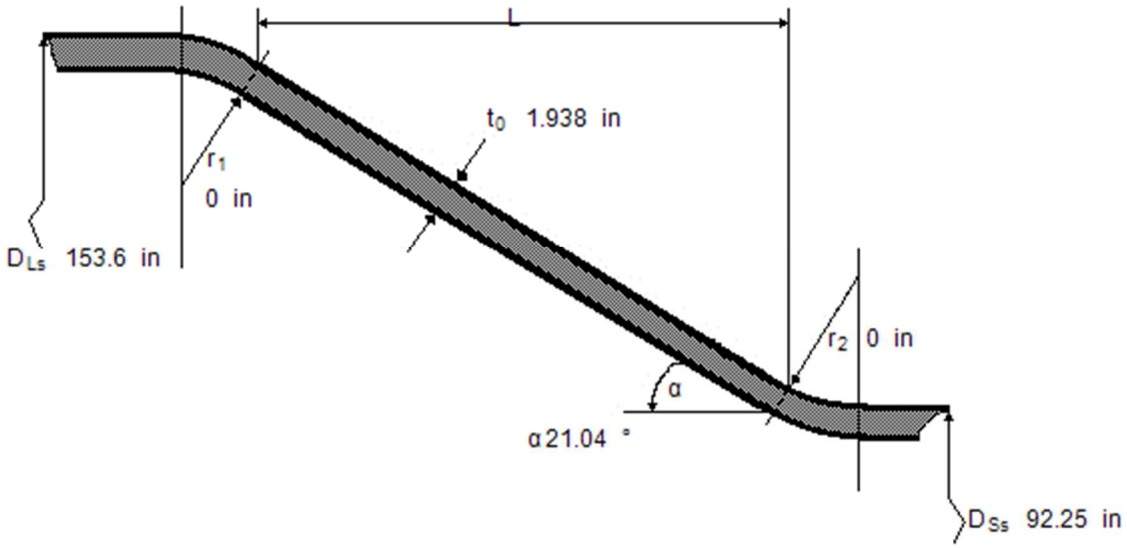
E4.4.8 Large and Small End - Formed heads pressure on convex side ASME BPVC VIII UG-33 and APP. 1, 2017 Edition

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

External design pressure	p_D	14.7	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**14.7**	psi
Calculation temperature	T_0	300	°F

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	
E-Modulus	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}	92.25	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	**79.79**	in
Design length		L_e	**63.85**	in
Ratio		L_e/D_L	**0.4156**	
Ratio		D_L/t_e	**90.81**	
Factor according to fig. 5-UGO-28.0		A	**0.004054**	
Factor (see material chart)		B	**16850**	psi
Factor	$2 \cdot \text{Min}(S_0; .9 \cdot B)$	S	**31589**	psi
Allowable external pressure	(for t0)	P	**247.4**	psi
Allowable pressure without hydrostatic head		MEP	**247.4**	psi
Required thickness	(for P0)	t	***0.3664***	in
Required thickness incl. allowances		$t+c_1+c_2$	***0.4914***	in

Remark

Equations

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

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

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

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

$$D_S = D_{Ss} + r_2 \cdot (1 - \cos(\alpha)) = 2343\ \text{mm} + 0\ \text{mm} \cdot (1 - 0.9333) = 2343\ \text{mm}$$

$$L = \frac{(D_L - D_S)}{2} \cdot \tan(\alpha) = \frac{(3902\ \text{mm} - 2343\ \text{mm})}{2} \cdot 0.3846 = 2027\ \text{mm}$$

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

$$L_2 = r_2 \cdot \left(\frac{D_{Ss}}{D_{Ls}}\right) \cdot \sin(\alpha) = 0\ \text{mm} \cdot 0.6005 \cdot 0.359 = 0\ \text{mm}$$

$$L_3 = \frac{L}{2} \cdot \frac{(D_L + D_S)}{D_{Ls}} = \frac{2027\ \text{mm}}{2} \cdot \frac{(3902\ \text{mm} + 2343\ \text{mm})}{3902\ \text{mm}} = 1622\ \text{mm}$$

$$L_e = L_1 + L_2 + L_3 = 0\ \text{mm} + 0\ \text{mm} + 1622\ \text{mm} = 1622\ \text{mm}$$

1) for $D_L/t_0 \geq 10$

$$Pa(B) = \frac{4 \cdot B}{3 \cdot \left(\frac{D_L}{t_0}\right)} = \frac{4 \cdot 116.2\ \text{N/mm}^2}{3 \cdot 90.81} = 1.706\ \text{N/mm}^2$$

UG-33 f-a) Step 6

$$Pa(E) = \frac{2 \cdot A \cdot E}{3 \cdot \left(\frac{D_L}{t_0}\right)} = \frac{2 \cdot 0.004054 \cdot 199948\ \text{N/mm}^2}{3 \cdot 90.81} = 5.951\ \text{N/mm}^2$$

UG-33 f-a) Step 7

2) for $D_L/t_0 < 10$

$$P_{a1} = \left[\frac{2.167}{\frac{D_L}{t_0}} - 0.0833 \right] \cdot B = \left[\frac{2.167}{90.81} - 0.0833 \right] \cdot 116.2\ \text{N/mm²} = -6.905\ \text{N/mm²}$$

UG-33 f-b) Step 2

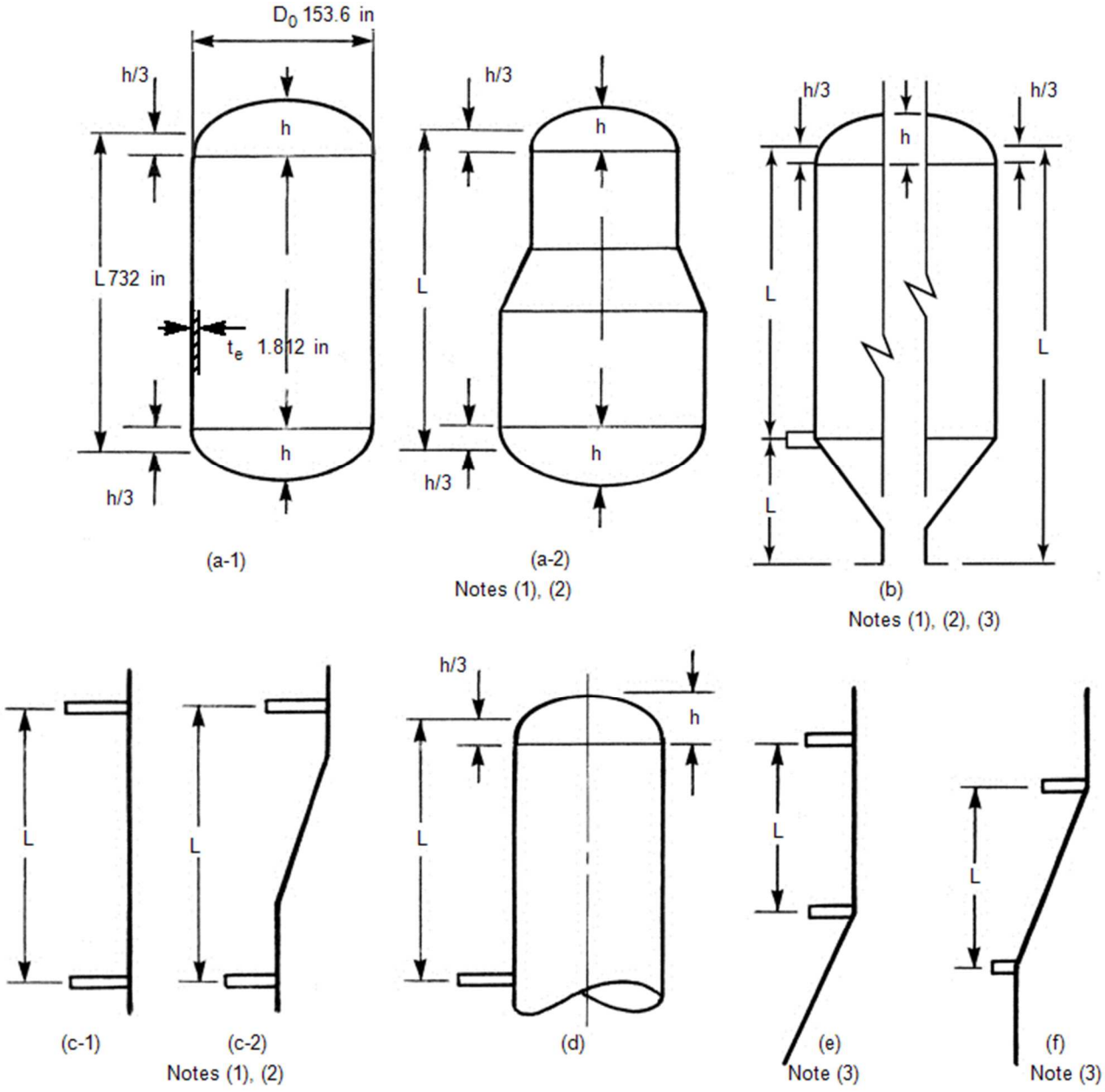
$$P_{a2} = \frac{2 \cdot S}{\frac{D_L}{t_0}} \cdot \left[1 - \frac{2 \cdot S}{\frac{D_L}{t_0}} \right] = \frac{2 \cdot 217.8\ \text{N/mm²}}{90.81} \cdot \left[1 - \frac{2 \cdot 217.8\ \text{N/mm²}}{90.81} \right] = 4.744\ \text{N/mm²}$$

UG-33 f-b) Step 3

Thickness of shells and tubes under external pressure ASME BPVC VIII UG-28 and Appendix I, 2017 Edition

Cylindrical shells under external pressure

External design pressure	p_D	14.7 psi
Hydrostatic head	D_p	0 psi
External calculation pressure	p_0	**14.7** psi
Calculation temperature	T_0	300 °F



Outside diameter	D_0	153.6 in
Design wall thickness	t_e	1.812 in
Wall thickness allowance	c_1	0 in
Allowance (corrosion)	c_2	0.125 in
Buckling length	L	732 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	2.829e+7	psi

Results

Effective thickness	t_0	**1.687**	in
Ratio	L/D_0	**4.765**	
Ratio	D_0/t_0	**91.03**	
Factor according to ASME-IID\Table G	A	**2.883e-4**	
Factor (see material chart)	B	**4141**	psi
Factor 2*Min(S_0;.9*B)	S	**7454**	psi
Required thickness acc. UG-28	t_{UG-28}	**24.25**	mm
Required thickness acc. UG-16	t_{UG-16}	1.5	mm
Required thickness	t	**0.9549**	in
Required thickness incl. allowances	$t+c_1+c_2$	**1.08**	in
Allowable excess pressure	P	**59.74**	psi
Allowable pressure without hydrostatic head	MAWP	**59.74**	psi

Remark

Equations

$$\frac{D_0}{t_0} \geq 10 \Leftrightarrow 91.03 \geq 10$$ UG-28 c) (1)

$$Pa(B) = \frac{4 \cdot B}{3 \cdot \frac{D_0}{t_0}} = \frac{4 \cdot 28.55\ \text{N/mm}^2}{3 \cdot 91.03} = 0.4182\ \text{MPa}$$ Step 6

$$Pa(E) = \frac{2 \cdot A \cdot E}{3 \cdot \frac{D_0}{t_0}} = \frac{2 \cdot 2.883\text{e-}4 \cdot 195067\ \text{N/mm}^2}{3 \cdot 91.03} = 0.4119\ \text{MPa}$$ Step 7

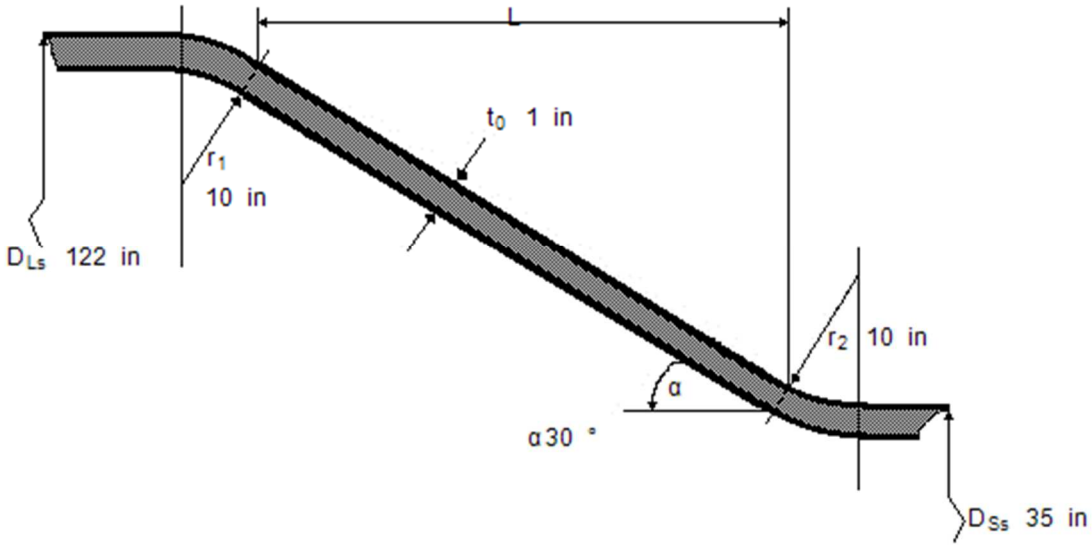
Formed heads pressure on convex side ASME BPVC VIII UG-33 and APP. 1, 2017 Edition

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

External design pressure	p_D	19.53	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**19.53**	psi
Calculation temperature	T_0	300	°F

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	
E-Modulus	E	2.9e+7	psi



Cone wall thickness with allowances	t_0	1	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0	in
Cone wall thickness without allowances	t	**1**	in

Is a cylinder connected, which does not act as line of support?			N	(Y/N)
Outside diameter	(wide end)	D_{Ls}	122	in
Knuckle radius	(wide end)	r_1	10	in
Outside diameter	(small end)	D_{Ss}	35	in
Knuckle radius	(small end)	r_2	10	in
Half apex angle (≤ 60°)		α	30	°

Results

Effective thickness	$t_e = t \cdot \cos(\alpha)$	t_e	**0.866**	in
Axial length of the cone		L	**73.02**	in
Design length		L_e	**53.42**	in
Ratio		L_e/D_L	**0.4427**	
Ratio		D_L/t_e	**139.3**	
Factor according to fig. 5-UGO-28.0		A	**0.001947**	
Factor (see material chart)		B	**14826**	psi
Factor	$2 \cdot \text{Min}(S_0;.9 \cdot B)$	S	**31589**	psi
Allowable external pressure	(for t0)	P	**141.9**	psi
Allowable pressure without hydrostatic head		MEP	**141.9**	psi
Required thickness	(for P0)	t	**0.3558**	in
Required thickness incl. allowances		$t+c_1+c_2$	**0.3558**	in

Remark

Equations

$cos(\alpha) = cos(\alpha) = cos(30°) = 0.866$

$sin(\alpha) = sin(\alpha) = sin(30°) = 0.5$

$tan(\alpha) = tan(\alpha) = tan(30°) = 0.5774$

$$D_L = D_{Ls} - r_1 \cdot (1 - \cos(\alpha)) = 3099\ \text{mm} - 254\ \text{mm} \cdot (1 - 0.866) = 3065\ \text{mm}$$

$$D_S = D_{Ss} + r_2 \cdot (1 - \cos(\alpha)) = 889\ \text{mm} + 254\ \text{mm} \cdot (1 - 0.866) = 923\ \text{mm}$$

$$L = \frac{(D_L - D_S)}{2} \cdot \tan(\alpha) = \frac{(3065\ \text{mm} - 923\ \text{mm})}{2} \cdot 0.5774 = 1855\ \text{mm}$$

$$L_1 = r_1 \cdot \sin(\alpha) = 254\ \text{mm} \cdot 0.5 = 127\ \text{mm}$$

$$L_2 = r_2 \cdot \left(\frac{D_{Ss}}{D_{Ls}}\right) \cdot \sin(\alpha) = 254\ \text{mm} \cdot 0.2869 \cdot 0.5 = 36.43\ \text{mm}$$

$$L_3 = \frac{L}{2} \cdot \frac{(D_L + D_S)}{D_{Ls}} = \frac{1855\ \text{mm}}{2} \cdot \frac{(3065\ \text{mm} + 923\ \text{mm})}{3099\ \text{mm}} = 1193\ \text{mm}$$

$$L_e = L_1 + L_2 + L_3 = 127\ \text{mm} + 36.43\ \text{mm} + 1193\ \text{mm} = 1357\ \text{mm}$$

1) for $D_L/t_0 \geq 10$

$$Pa(B) = \frac{4 \cdot B}{3 \cdot \left(\frac{D_L}{t_0}\right)} = \frac{4 \cdot 102.2\ \text{N/mm}^2}{3 \cdot 139.3} = 0.9783\ \text{N/mm}^2$$

UG-33 f-a) Step 6

$$Pa(E) = \frac{2 \cdot A \cdot E}{3 \cdot \left(\frac{D_L}{t_0}\right)} = \frac{2 \cdot 0.001947 \cdot 199948\ \text{N/mm}^2}{3 \cdot 139.3} = 1.862\ \text{N/mm}^2$$

UG-33 f-a) Step 7

2) for $D_L/t_0 < 10$

$$P_{a1} = \left[\frac{2.167}{\frac{D_L}{t_0}} - 0.0833 \right] \cdot B = \left[\frac{2.167}{139.3} - 0.0833 \right] \cdot 102.2\ \text{N/mm²} = -6.925\ \text{N/mm²}$$

UG-33 f-b) Step 2

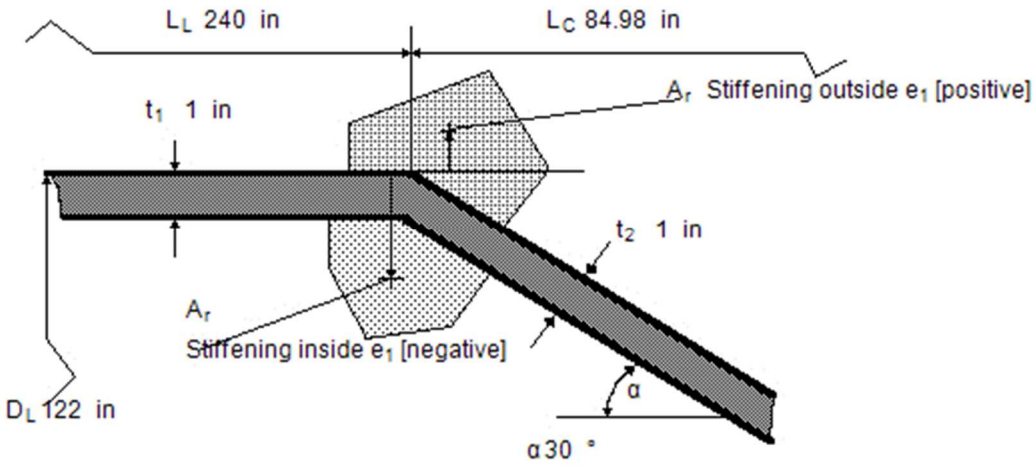
$$P_{a2} = \frac{2 \cdot S}{\frac{D_L}{t_0}} \cdot \left[1 - \frac{2 \cdot S}{\frac{D_L}{t_0}} \right] = \frac{2 \cdot 217.8\ \text{N/mm²}}{139.3} \cdot \left[1 - \frac{2 \cdot 217.8\ \text{N/mm²}}{139.3} \right] = 3.104\ \text{N/mm²}$$

UG-33 f-b) Step 3

E4.4.8 Large End/Line-of-support - Formed heads pressure on convex side ASME BPVC VIII UG-33 and APP. 1, 2017 Edition

Moment of inertia at the wide end of a cone-cylinder-juncture under external pressure acc. App. 1-8 (Line-of-support)

External design pressure	p_D	14.7	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**14.7**	psi
Calculation temperature	T_0	300	°F
Axial load (for positive tension)	f_1	145	lbf/in



Cylinder

Design wall thickness	t_1	1	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0	in
Final thickness without allowances	t_s	**1**	in
Required thickness without allowances (UG-28)	t_{1r}	0.5205	in
Required thickness with allowances (UG-28)	t_{1r+}	**0.5205**	in
Outside diameter	D_L	122	in
Tip radius ($=D_L/2$)	R_L	**61**	in
Buckling length	L_L	240	in

Cone

Design wall thickness	t_2	1	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0	in
Final thickness without allowances	t_c	**1**	in
Required thickness without allowances (UG-33)	t_{2r}	0.3358	in
Required thickness with allowances (UG-33)	t_{2r+}	**0.3358**	in
Half apex angle (≤ 60°)	α	30	°
Buckling length	L_C	84.98	in

Stiffening ring

Material	K02700-SA-516-70-Class:-Size:		
Spec. Min. Yield	S_y	2.9e+7	psi
Applicable material chart	Fig	CS-2	
Centroidal distance	e_1		in
Cross sectional area	A_r	0	in²
Moment of inertia	I_r		in^4

Results

Equivalent length	M	**134.7**	in
Effective load	F_L	**2064**	lbf/in
Reference area	A_{TL}	**162.5**	in²
Factor	B	**1162**	psi
Factor (see material chart)	A	**8.142e-5**	
Required moment of inertia	I_s	**14.07**	in^4
Required moment of inertia	I'_s	**18.07**	in^4
Length of support	$0.55\cdot\sqrt{(D\cdot t_s)}$	**6.075**	in
Available moment of inertia	I'		in^4

Remark **Stiffening required**

Equations

$cos(\alpha)=cos(\alpha)=cos(30°)=0.866$

$sin(\alpha)=sin(\alpha)=sin(30°)=0.5$

$tan(\alpha)=tan(\alpha)=tan(30°)=0.5774$

$R_S=R_L-L_C\cdot\sin(\alpha)=1549\text{ mm}-2158\text{ mm}\cdot 0.5=445\text{ mm}$

$$M=\frac{-R_L\cdot\tan(\alpha)}{2}+\frac{L_L}{2}+\frac{RL^2-RS^2}{3\cdot R_L\cdot\tan(\alpha)}=$$

$$\frac{-1549\text{ mm}\cdot 0.5774}{2}+\frac{6096\text{ mm}}{2}+\frac{(1549\text{ mm})^2-(445\text{ mm})^2}{3\cdot 1549\text{ mm}\cdot 0.5774}=3421\text{ mm}$$

App. 1-8 b-3) Step 1

$$F_L=P_0\cdot M+f_1\cdot\tan(\alpha)=$$

$1.014\text{ bar}\cdot 3421\text{ mm}+25.39\text{ N/mm}\cdot 0.5774=361.4\text{ N/mm}$

App. 1-8 b-3) Step 1

$$A_{TL}=L_L\cdot\frac{t_s}{2}+L_C\cdot\frac{t_c}{2}+A_s=$$

$$6096\text{ mm}\cdot\frac{25.4\text{ mm}}{2}+2158\text{ mm}\cdot\frac{25.4\text{ mm}}{2}+0\text{ mm²}=104831\text{ mm²}$$

App. 1-8 a)

$$B=\frac{3}{4}\cdot\frac{F_L\cdot D_L}{A_{TL}}=\frac{3}{4}\cdot\frac{361.4\text{ N/mm}\cdot 3099\text{ mm}}{104831\text{ mm²}}=8.013\text{ N/mm²}$$

App. 1-8 b-3) Step 1

$$I_s=A\cdot D_L^2\cdot\frac{A_{TL}}{14}=8.142\text{e-}5\cdot(3099\text{ mm})^2\cdot\frac{104831\text{ mm²}}{14}=5854591\text{ mm^4}$$

App. 1-8 b-3) Step 6

$$I'_s=A\cdot D_L^2\cdot\frac{A_{TL}}{10.9}=8.142\text{e-}5\cdot(3099\text{ mm})^2\cdot\frac{104831\text{ mm²}}{10.9}=7519658\text{ mm^4}$$

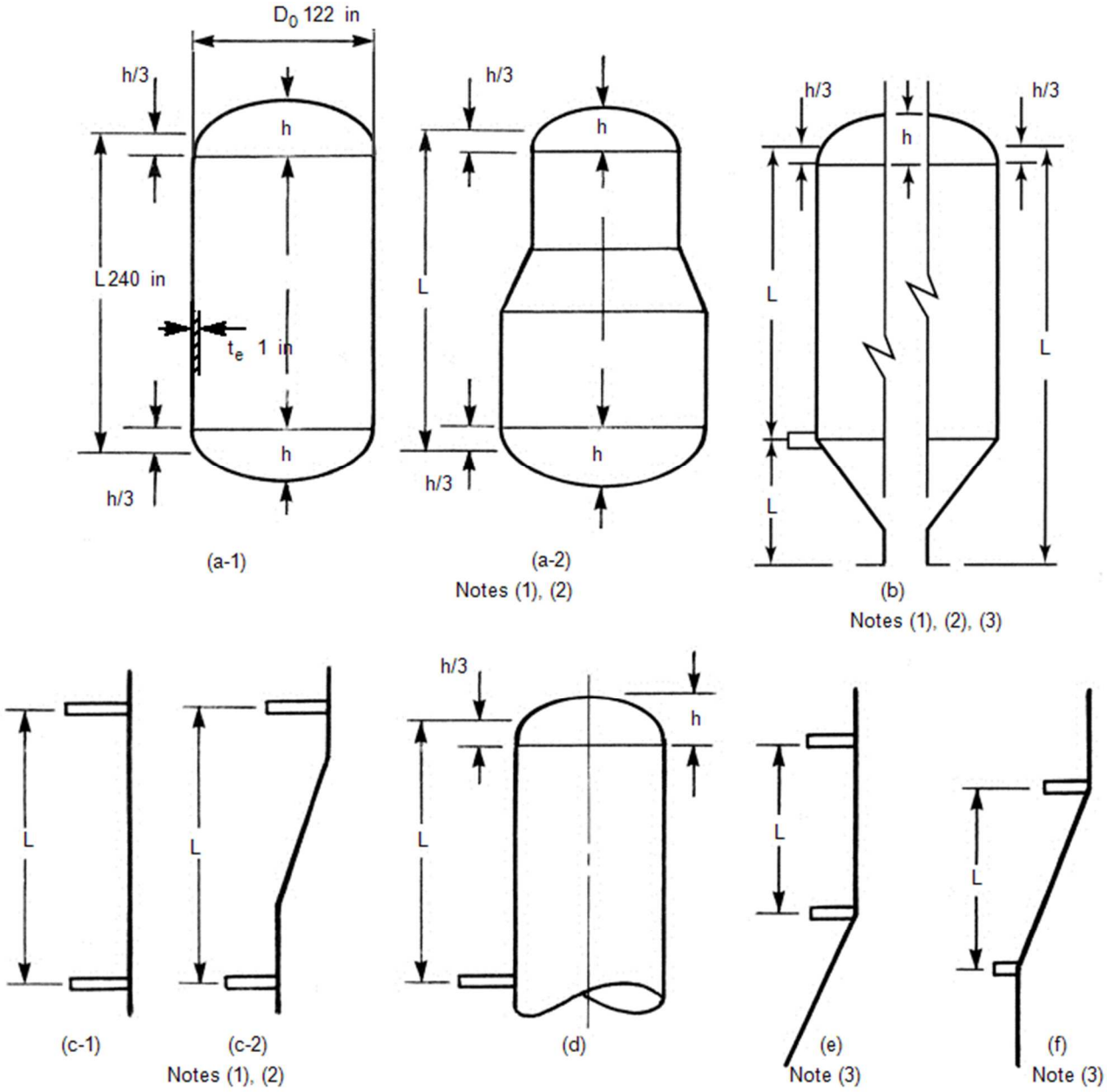
App. 1-8 b-3) Step 6

$$0.55\cdot\sqrt{(D\cdot t_s)}=0.55\cdot\sqrt{(3099\text{ mm}\cdot 25.4\text{ mm})}=154.3\text{ mm}$$

Thickness of shells and tubes under external pressure ASME BPVC VIII UG-28 and Appendix I, 2017 Edition

Cylindrical shells under external pressure

External design pressure	p_D	14.7	psi
Hydrostatic head	D_p	0	psi
External calculation pressure	p_0	**14.7**	psi
Calculation temperature	T_0	300	°F



Outside diameter	D_0	122	in
Design wall thickness	t_e	1	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0	in
Buckling length	L	240	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	2.829e+7	psi

Results

Effective thickness	t_0	**1**	in
Ratio	L/D_0	**1.967**	
Ratio	D_0/t_0	**122**	
Factor according to ASME-IID\Table G	A	**4.844e-4**	
Factor (see material chart)	B	**6974**	psi
Factor 2*Min(S_0;.9*B)	S	**12553**	psi
Required thickness acc. UG-28	t_{UG-28}	**13.22**	mm
Required thickness acc. UG-16	t_{UG-16}	1.5	mm
Required thickness	t	**0.5205**	in
Required thickness incl. allowances	$t+c_1+c_2$	**0.5205**	in
Allowable excess pressure	P	**74.89**	psi
Allowable pressure without hydrostatic head	MAWP	**74.89**	psi

Remark

Equations

$$\frac{D_0}{t_0} \geq 10 \Leftrightarrow 122 \geq 10$$ UG-28 c) (1)

$$Pa(B) = \frac{4 \cdot B}{3 \cdot \frac{D_0}{t_0}} = \frac{4 \cdot 48.08\ \text{N/mm}^2}{3 \cdot 122} = 0.5255\ \text{MPa}$$ Step 6

$$Pa(E) = \frac{2 \cdot A \cdot E}{3 \cdot \frac{D_0}{t_0}} = \frac{2 \cdot 4.844\text{e-}4 \cdot 195067\ \text{N/mm}^2}{3 \cdot 122} = 0.5163\ \text{MPa}$$ Step 7

Appendix: Material documentation

Section 2: Zylinder/UG33
Section 2: Kegel/UG33
Section 2: Versteifung/UG33
Section 3: Verstärkung/UG33
Section 4: Zylinder/UG33
Section 4: Kegel/UG33
Section 5: Verstärkung/UG33
Section 6: Boden/UG33
Section 7: Schale/UG28
Section 8: Boden/UG33
Section 9: Verstärkung/UG33
Section 10: Schale/UG28

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]: 1,013536
Thickness [mm]: 46,04 Outside diameter [mm]: 3902,07

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	138,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	138,00
Modulus of elasticity [kN/mm²]:	202	195,0667

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.

--
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. längs %	Rupture elong. quer %

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	

a 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					