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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

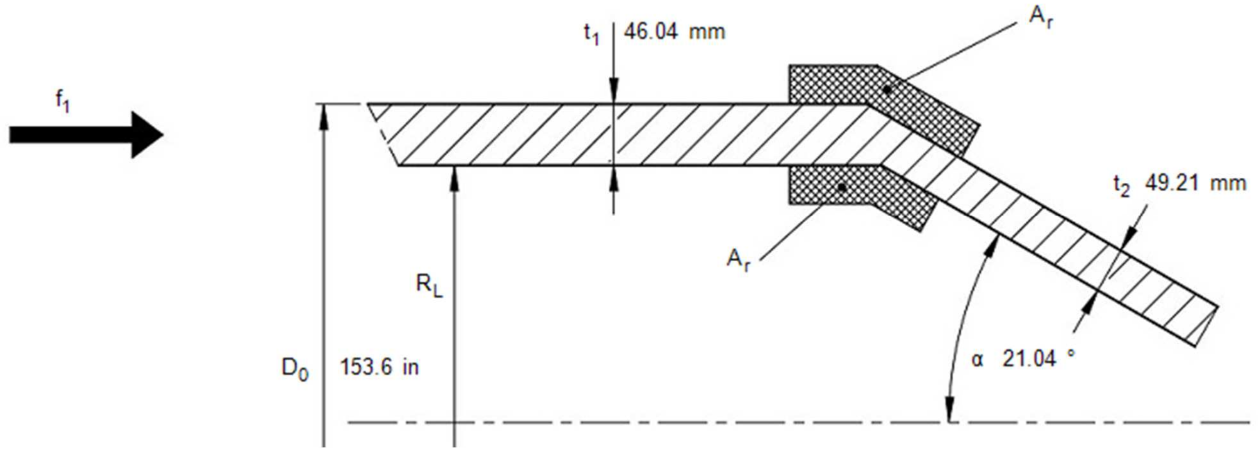
Comment
Results for example E4.3.7-8 acc. ASME and Lauterbach Verfahrenstechnik GmbH (LV)
The LV-program uses formulas for thick Shells acc.ASME VIII Div.1 UG32 and App.1.

Equations		Value
Conversion factor	mm2in = 0.03937	0.03937
.	mm^2toin^2=0.00155	0.00155
'Results Ex. E4.3.7 LV and ASME Larg End		0
Del acc.to LV = #58(2)		30
Del acc. to Asme = 30		30
Required thickness t acc. LV	t7 = mm2in*#64(2)	1.447
Required thickness t ASME	t7Asme = 1.4482	1.448
Difference in %	Diff1 = (t7-t7Asme)/t7Asme*100	-0.08549
'Results Ex. E4.3.7 LV and ASME Small End		0
Del acc.to LV = #58(3)		11.73
Del acc. to Asme = 11.73		11.73
Required area acc. LV	Ars = 0.00155*#62(3)	3.235
Required area ASME	ArsAsme = 3.2362	3.236
Difference in %	Diff2a = (Ars-ArsAsme)/ArsAsme*100	-0.02528
Required area acc. LV	Aes = 0.00155*#67(3)	6.284
Required area ASME	AesAsme = 6.2772	6.277
Difference in %	Diff2b = (Aes-AesAsme)/AesAsme*100	0.113
'Results Ex. E4.3.8 LV and ASME		0
Required thickness t acc. LV	t = mm2in*#15(4)	0.6773
Required thickness tk ASME	tkAsme = 0.6778	0.6778
Difference in %	Diff3 = (t-tkAsme)/tkAsme*100	-0.06903
Required thickness t1 acc. LV	t1 = mm2in*#120(4)	0.9741
Required thickness tc ASME	tcAsme = 0.9749	0.9749
Difference in %	Diff4 = (t1-tcAsme)/tcAsme*100	-0.07963
'Maximum difference between LV and ASME		0
Dmax = Max(|Diff1|;|Diff2a|;|Diff2b|;|Diff3|;|Diff4|)		0.113

E4.3.7 Large End - Dished heads and cones under internal pressure ASME VIII UG-32 and APPENDIX-1 BPVC 2017 Edition

Cone-to-cylinder junction (wide end)

Type of reinforcing ring			
(0 = no, 1 = at the cylinder, 2 = at the cone)		0	
Without stiffener			
Design pressure	p_D	356	psi
Hydrostatic head	D_p	0	bar
Calculation pressure	p_0	**24.55**	bar
Calculation temperature	T_0	300	°F
Axial load based on circumference (for compression negative)	f_1	0	lbf/in



Cylinder

Outside diameter		D_0	153.6	in
Final wall thickness		t_1	46.04	mm
Material	K02700-SA-516-70-Class:-Size:			
Wall thickness allowance		c_1	0	mm
Allowance (corrosion)		c_2	3.175	mm
Thickness without allowances		t_s	**42.86**	mm
Inside radius	(= $D_0/2-t_s$)	R_L	**1908**	mm
Allowable stress		S_s	138	N/mm²
Modulus of elasticity		E_s	195067	N/mm²
Joint efficiency factor		E_1	1	

Cone

Half-apex angle (≤30°)		α	21.04	°
Final wall thickness		t_2	49.21	mm
Material	K02700-SA-516-70-Class:-Size:			
Wall thickness allowance		c_1	0	mm
Allowance (corrosion)		c_2	3.175	mm
Effective thickness		t_c	**46.04**	mm
Allowable stress		S_c	138	N/mm²
Modulus of elasticity		E_c	195067	N/mm²
Joint efficiency factor		E_2	1	

Results

Geometrical conditions
valid

Strength condition
Wall thickness acceptable

Factor				k	**1**	
Ratio			P_0/S_sE_1		**0.01779**	
Angle	(Reinforcement required if Δ < α	21.04 °	)	Δ	**30**	°
Effective load				Q_L	**13371**	lbf/in
Required thickness cylinder (UG-27)				t	**1.351**	in
with allowances	(t_1	46.04 mm	≥t+)	t+	**1.476**	in
Required thickness cone (UG-32)				t_r	**36.75**	mm
with allowances	(t_2	49.21 mm	$≥t_r$+)	t_r+	**39.93**	mm
Required cross sectional area				A_{rL}	**0**	in²
Available cross section				A_{eL}	**5296**	mm²
Required area of reinforcement				A_r	**0**	in²
Available area of reinforcement			$b_v \cdot t_v$	A_v	0	mm²
Maximum distance from the connection point of the						
complete reinforcing area			$\sqrt{[R_L \cdot t_s]}$		**286**	mm
centroid of reinforcing area			$0.25 \cdot \sqrt{[R_L \cdot t_s]}$		**71.49**	mm

Equations

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

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

$$Q_L=P_0 \cdot \frac{R_L}{2}+f_1=24.55\ \text{bar} \cdot \frac{1908\ \text{mm}}{2}+0\ \text{N/mm}=2342\ \text{N/mm}$$

$$A_{rL}=\frac{k \cdot Q_L \cdot R_L}{S_s \cdot E_1} \cdot \left[1-\frac{D_{el}}{\alpha}\right] \cdot \tan(\alpha)=\frac{1 \cdot 2342\ \text{N/mm} \cdot 1908\ \text{mm}}{138\ \text{N/mm}^2 \cdot 1} \cdot \left[1-\frac{30°}{21.04°}\right] \cdot 0.3846=0\ \text{mm}^2$$

$$t=\frac{P_0 \cdot R_L}{S_s \cdot E_1-0.6 \cdot P_0}=\frac{24.55\ \text{bar} \cdot 1908\ \text{mm}}{138\ \text{N/mm}^2 \cdot 1-0.6 \cdot 24.55\ \text{bar}}=34.3\ \text{mm}$$

$$t_r=\frac{P_0 \cdot \frac{R_L}{\cos(\alpha)}}{S_c \cdot E_2-0.6 \cdot P_0}=\frac{24.55\ \text{bar} \cdot \frac{1908\ \text{mm}}{0.9333}}{138\ \text{N/mm}^2 \cdot 1-0.6 \cdot 24.55\ \text{bar}}=36.75\ \text{mm}$$

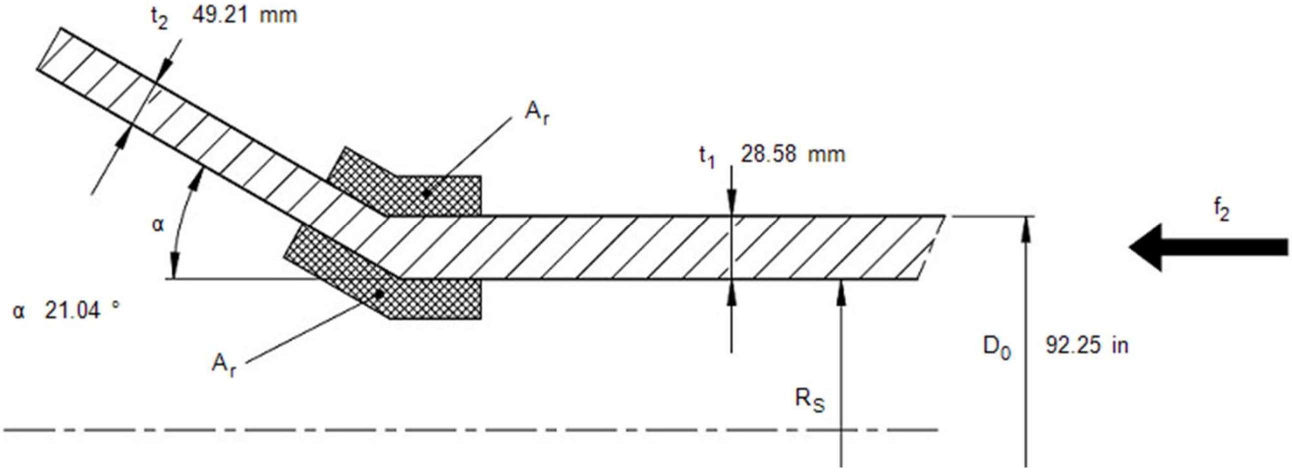
$$A_{eL}=(t_s-t) \cdot \sqrt{R_L \cdot t_s}+(t_c-t_r) \cdot \sqrt{R_L \cdot \frac{t_c}{\cos(\alpha)}}=$$

$$(42.86\ \text{mm}-34.3\ \text{mm}) \cdot \sqrt{1908\ \text{mm} \cdot 42.86\ \text{mm}}+(46.04\ \text{mm}-36.75\ \text{mm}) \cdot \sqrt{1908\ \text{mm} \cdot \frac{46.04\ \text{mm}}{0.9333}}=5296\ \text{mm}^2$$

E4.3.7 Small End - Dished heads and cones under internal pressure ASME VIII UG-32 and APPENDIX-1 BPVC 2017 Edition

Cone-to-cylinder junction (small end)

Type of reinforcing ring (0 = no, 1 = at the cylinder, 2 = at the cone)		0	
Without stiffener			
Design pressure	p_D	356	psi
Hydrostatic head	D_p	0	bar
Calculation pressure	p_0	**24.55**	bar
Calculation temperature	T_0	300	°F
Axial load based on circumference (for compression negative)	f_2	396.9	lbf/in



Cylinder

Outside diameter		D_0	92.25	in
Final wall thickness		t_1	28.58	mm
Material	K02700-SA-516-70-Class:-Size:			
Wall thickness allowance		c_1	0	mm
Allowance (corrosion)		c_2	3.175	mm
Effective thickness		t_s	**25.4**	mm
Inside radius	(= $D_0/2-t_s$)	R_S	**1146**	mm
Allowable stress		S_s	138	N/mm²
Modulus of elasticity		E_s	195067	N/mm²
Joint efficiency factor		E_1	1	

Cone

Half-apex angle (≤30°)		α	21.04	°
Final wall thickness		t_2	49.21	mm
Material	K02700-SA-516-70-Class:-Size:			
Wall thickness allowance		c_1	0	mm
Allowance (corrosion)		c_2	3.175	mm
Thickness without allowances		t_c	**46.04**	mm
Allowable stress		S_c	138	N/mm²
Modulus of elasticity		E_c	195067	N/mm²
Joint efficiency factor		E_2	1	

Results

Geometrical conditions
valid

Strength condition
Wall thickness acceptable

Factor			k	**1**	
Ratio		P_0/S_sE_1		**0.01779**	
Angle			Δ	**11.73**	°
Effective load			Q_S	**1476**	N/mm
Required thickness cylinder (UG-27)			t	**0.8113**	in
with allowances	(t_1 28.58 mm	≥t+)	t+	**0.9363**	in
Required thickness cone (UG-32)			t_r	**22.08**	mm
with allowances	(t_2 49.21 mm	$≥t_r$+)	t_r+	**25.25**	mm
Required cross sectional area			A_{rS}	**2087**	mm²
Available cross section			A_{eS}	**4054**	mm²
Required area of reinforcement			A_r	**0**	in²
Available area of reinforcement		$b_v \cdot t_v$	A_v	**0**	mm²
Maximum distance from the connection point of the					
complete reinforcing area		$\sqrt{[R_L \cdot t_s]}$		**229.7**	mm
centroid of reinforcing area		$0.25 \cdot \sqrt{[R_L \cdot t_s]}$		**57.43**	mm

Equations

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

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

$$QS=P0 \cdot \frac{RS}{2}+f2=24.55\text{ bar} \cdot \frac{1146\text{ mm}}{2}+69.5\text{ N/mm}=1476\text{ N/mm}$$

$$ArS=\frac{k \cdot QS \cdot RS}{SS \cdot E1} \cdot \left[1-\frac{Del}{\alpha}\right] \cdot tan(\alpha)=\frac{1 \cdot 1476\text{ N/mm} \cdot 1146\text{ mm}}{138\text{ N/mm}^2 \cdot 1} \cdot \left[1-\frac{11.73°}{21.04°}\right] \cdot 0.3846=2087\text{ mm}^2$$

$$t=\frac{P0 \cdot RS}{Ss \cdot E1-0.6 \cdot P0}=\frac{24.55\text{ bar} \cdot 1146\text{ mm}}{138\text{ N/mm}^2 \cdot 1-0.6 \cdot 24.55\text{ bar}}=20.61\text{ mm}$$

$$tr=\frac{P0 \cdot \frac{RS}{(cos(\alpha))}}{Sc \cdot E2-0.6 \cdot P0}=\frac{24.55\text{ bar} \cdot \frac{1146\text{ mm}}{0.9333}}{138\text{ N/mm}^2 \cdot 1-0.6 \cdot 24.55\text{ bar}}=22.08\text{ mm}$$

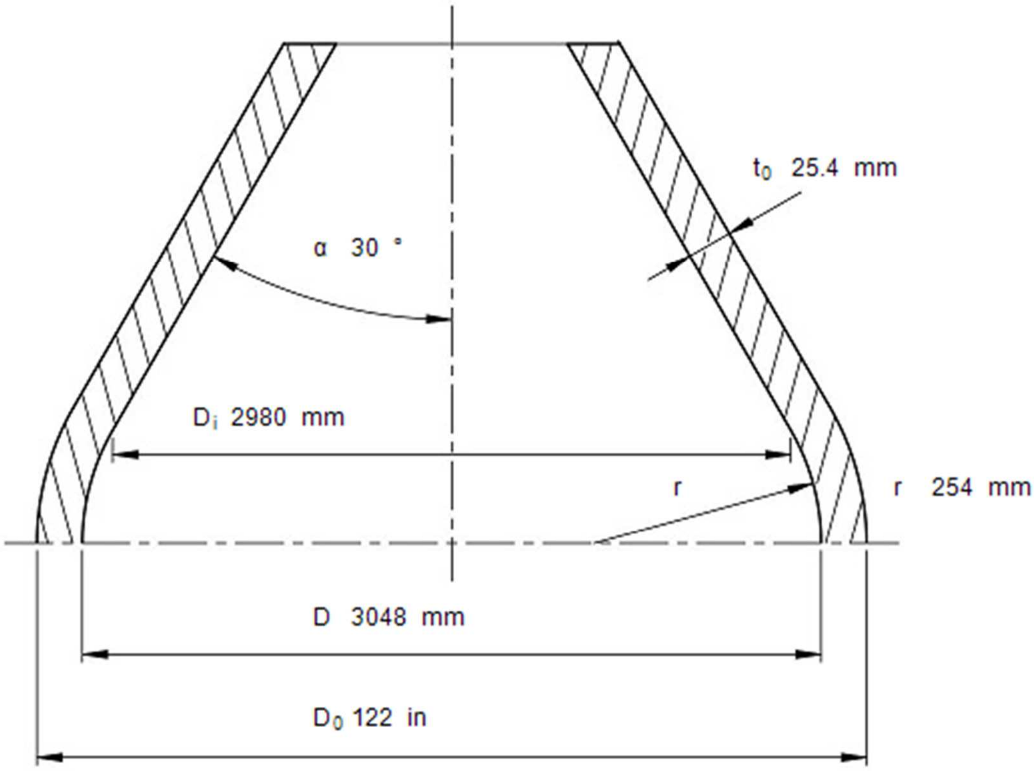
$$AeS=0.78 \cdot \sqrt{RS \cdot ts} \cdot \left[(ts-t)+\frac{(tc-tr)}{cos(\alpha)}\right]=$$

$$0.78 \cdot \sqrt{1146\text{ mm} \cdot 25.4\text{ mm}} \cdot \left[(25.4\text{ mm}-20.61\text{ mm})+\frac{(46.04\text{ mm}-22.08\text{ mm})}{0.9333}\right]=4054\text{ mm}^2$$

E4.3.8 - Dished heads and cones under internal pressure ASME VIII UG-32 and APPENDIX-1 BPVC 2017 Edition

Toriconical sections

Design pressure	p_D	285.4	psi
Hydrostatic head	D_p	0	bar
Calculation pressure	p_0	**19.68**	bar
Calculation temperature	T_0	300	°F
Final wall thickness	t_e	25.4	mm
Wall thickness allowance	c_1	0	mm
Allowance (corrosion)	c_2	0	mm
Effective thickness witout allowances	t_0	**25.4**	mm



Outside diameter of cylindrical shell		D_0	122	in
Inside diameter of cylindrical shell	$(= D_0 - 2t_0)$	D	**3048**	mm
Semi-apex angle		α	30	°
Knuckle radius (≥0.06·Da, ≥3·t_e)		r	254	mm
Weld joint efficiency factor		E	1	

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

Allowable stress	S	**138**	N/mm²

Calculation

Largest inside diameter of cone		D_i	**2980**	mm
Equivalent radius		L	**1720**	mm
Ratio		L/r	**6.774**	
Factor		M	**1.401**	
Required knuckle thickness		t	**17.2**	mm
Allowable inside pressure of knuckle		P	**29.03**	bar
Calculation diameter of cone		D_1	**2980**	mm
Required cone thickness at D_1		t_1	**24.74**	mm
Allowable inside pressure of cone		P_1	**20.19**	bar
Remark				
Required thickness incl. allowances	$t+c_1+c_2$	t+	**24.74**	mm
Allowable excess pressure	$Min(P, P_1)$	P_m	**20.19**	bar
Allowable excess pressure without hydr. Head		MAWP	**20.19**	bar

Geometrical conditions

valid

Strength condition

Wall thickness acceptable

Equations knuckle

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

$$D_i=D-2\cdot r\cdot(1-\cos(\alpha))=3048\text{ mm}-2\cdot 254\text{ mm}\cdot(1-0.866)=2980\text{ mm}$$

$$L=\frac{D_i}{2\cdot\cos(\alpha)}=\frac{2980\text{ mm}}{2\cdot 0.866}=1720\text{ mm}$$

$$t=\frac{P_0\cdot L\cdot M}{2\cdot S\cdot E-0.2\cdot P_0}=\frac{19.68\text{ bar}\cdot 1720\text{ mm}\cdot 1.401}{2\cdot 138\text{ N/mm²}\cdot 1-0.2\cdot 19.68\text{ bar}}=17.2\text{ mm}$$

$$P=\frac{2\cdot S\cdot E\cdot t_0}{L\cdot M+0.2\cdot t_0}=\frac{2\cdot 138\text{ N/mm²}\cdot 1\cdot 25.4\text{ mm}}{1720\text{ mm}\cdot 1.401+0.2\cdot 25.4\text{ mm}}=2.903\text{ MPa}$$

Equations cone

$$t_1=\frac{P_0\cdot D_1}{2\cdot\cos(\alpha)\cdot(S\cdot E-0.6\cdot P_0)}=\frac{19.68\text{ bar}\cdot 2980\text{ mm}}{2\cdot 0.866\cdot(138\text{ N/mm²}\cdot 1-0.6\cdot 19.68\text{ bar})}=24.74\text{ mm}$$

$$P=\frac{2\cdot S\cdot E\cdot t_0\cdot\cos(\alpha)}{D_1+1.2\cdot t_0\cdot\cos(\alpha)}=\frac{2\cdot 138\text{ N/mm²}\cdot 1\cdot 25.4\text{ mm}\cdot 0.866}{2980\text{ mm}+1.2\cdot 25.4\text{ mm}\cdot 0.866}=2.019\text{ MPa}$$

Appendix: Material documentation

Section 2: Zylinder/UG32
Section 2: Kegel/UG32
Section 3: Zylinder/UG32
Section 3: Kegel/UG32
Section 4: Boden/UG32

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]: 0
Thickness [mm]: 46,04 Outside diameter [mm]: 3901,76

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.

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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. 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

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	100°C	200°C	300°C	400°C	500°C	600°C	700°C	800°C	Heat	Heat
(20 °C)									cond.	capac.
kg/dm³	10E-6/K	10E-6/K	10E-6/K	10E-6/K	10E-6/K	10E-6/K	10E-6/K	10E-6/K	W/Km	J/kgK
7,85	12,1	12,7	13,3	13,8	14,4	-	-	-		