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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

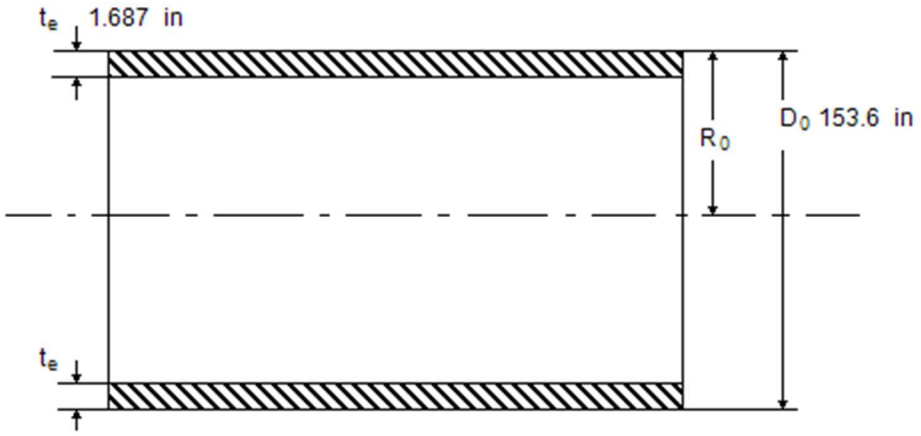
Comment
Results for example E4.5.1-6 acc. ASME and Lauterbach Verfahrenstechnik GmbH (LV)
The LV-program uses formulas for Shells Openings in Shells and Heads acc.UG37

Equations		Value
Conversion factor	mm2in = 0.03937	0.03937
.	mm^2toin^2=0.00155	0.00155
'Results Ex. E4.5.1 LV and ASME		0
Required area A acc. LV	A1 = 0.00155*#35(3)	21.98
Required area A ASME	A1Asme = 21.9651	21.97
Difference in %	Diff11 = (A1-A1Asme)/A1Asme*100	0.08691
Available area acc. LV	A1av = 0.00155*#38(3)	43.37
Available area ASME	A1avAsme = 43.3876	43.39
Difference in %	Diff12 = (A1av-A1avAsme)/A1avAsme*100	-0.04262
'Results Ex. E4.5.2 LV and ASME Step5 with F=1		0
Required area acc. LV	A2 = 0.00155*#35(1)	10.64
Required area ASME	A2Asme = 10.6379	10.64
Difference in %	Diff21 = (A2-A2Asme)/A2Asme*100	-3.76e-4
Available area Aav acc. LV	A2av = 0.00155*#38(1)	17.75
Available area Aav ASME	A2avAsme = 17.7531	17.75
Difference in %	Diff22 = (A2av-A2avAsme)/A2avAsme*100	0.002873
'Results Ex. E4.5.3 LV and ASME		0
Available area Aav acc. LV	A3av = 0.00155*#38(7)	10.71
Available area Aav Asme	A3avAsme = 10.8649	10.86
Difference in %	Diff3 = (A3av-A3avAsme)/A3avAsme*100	-1.438
'Results Ex. E4.5.4 LV and ASME		0
Available area acc. LV	A4av = 0.00155*#38(12)	33.93
Available area ASME	A4avAsme = 33.6476	33.65
Difference in %	Diff4 = (A4av-A4avAsme)/A4avAsme*100	0.8371
'Results Ex. E4.5.5 LV and ASME		0
Available area Aav acc. LV	A5av = 0.00155*#38(10)	23.38
Available area Aav ASME	A5avAsme = 23,3748	23.37
Difference in %	Diff5 = (A5av-A5avAsme)/A5avAsme*100	9.412e-4
'Results Ex. E4.5.6 LV and ASME		0
Available area Aav acc. LV	A6av = 0.00155*#38(14)	1.143
Available area Aav ASME	A6avAsme = 1.1416	1.142
Difference in %	Diff6 = (A6av-A6avAsme)/A6avAsme*100	0.1554
'Maximum difference between LV and ASME		0
Dmax = Max(|Diff11|;|Diff12|;|Diff21|;|Diff22|;|Diff3|;|Diff4|;|Diff5|;|Diff6|)		1.438

Thickness of shells under internal pressure ASME BPVC VIII UG-27 & APPENDIX-1, 2017 Edition

Cylindrical shells

Design pressure	p_D	356	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**356**	psi
Calulation temperature	T_0	300	°F



Outside diameter	D_0	153.6	in
Design wall thickness	t_e	1.687	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Weld joint efficiency	E	1	
Circumferential weld joint efficiency for Eq. 2	E_c		

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

Allowable stress	S	20015	psi

Results

Outside radius	R_0	**76.81**	in
Effective thickness	t_0	**1.563**	in

Calculation as thin shell is applicable				**Yes**	
Required thickness	$t(R_0)$			t(R)	
thin shell acc. UG-27		**1.357**	in		**1.353** in
thick shell (not applicable)		**1.354**	in		**1.35** in
Minimum wall thickness acc. UG-16				t_{UG-16} 0.05906	in
Required wall thickness for circumferential seam				t_{long}	in
t = Max{Min[t(R);t(R_0)],t_{UG-16}}				t ***1.353***	in
with allowances				$t+c_1+c_2$ **1.478**	in

Allowable excess pressure	P	**410.5**	psi
Allowable excess pressure for longitudinal stress for Eq. (2)	P_{long}		psi
Allowable excess pressure without hydrostatic head	MAWP	**410.5**	psi

Remark

For calculation of openings according to UG-37

Required thickness	t(E=1)	**1.353**	in

Allowable unreinforced opening diameter dA for welded, brazed, and flued connections acc. UG 36(c)3

dA ≤ 89 mm for t ≤10 mm	or	dA ≤ 3 1/2 in for t ≤3/8 in
dA ≤ 60 mm for t > 10 mm	or	dA ≤ 2 3/8 in for t > 3/8 in

For a vessel thickness > 2*t(E=1)+c_1+c_2 , the reinforcement of the vessel alone is sufficient for unreinforced openings, unless additional conditions acc. to UG-37 apply.

Equations

$P_0 = 0.1 \cdot p_0 = 0.1 \cdot 24.55\ \text{bar} = 24.55\ \text{bar}$

$R_0 = \frac{D_0}{2} = \frac{3902\ \text{mm}}{2} = 1951\ \text{mm}$

$t+c1+c2 = t + c_1 + c_2 = 34.36\ \text{mm} + 0\ \text{mm} + 3.175\ \text{mm} = 37.54\ \text{mm}$

corroded inside radius $R = R_0 - t_0 = 1951\ \text{mm} - 39.69\ \text{mm} = 1911\ \text{mm}$

1) Thin shell For

$P_0 \le 0.385 \cdot S \cdot E \Leftrightarrow 24.55\ \text{bar} \le 53.13\ \text{N/mm}^2$

and

with the inside radius R

$t_e \le \frac{(R_0 - t_e)}{2} \Leftrightarrow 42.86\ \text{mm} \le 954.1\ \text{mm}$

$t(R) = \frac{P_0 \cdot R}{S \cdot E - 0.6 \cdot P_0} = \frac{24.55\ \text{bar} \cdot 1911\ \text{mm}}{138\ \text{N/mm}^2 \cdot 1 - 0.6 \cdot 24.55\ \text{bar}} = 34.36\ \text{mm}$ UG-27 (1)

$P(R) = \frac{S \cdot E \cdot t_0}{R + 0.6 \cdot t_0} = \frac{138\ \text{N/mm}^2 \cdot 1 \cdot 39.69\ \text{mm}}{1911\ \text{mm} + 0.6 \cdot 39.69\ \text{mm}} = 2.83\ \text{MPa}$ UG-27 (1)

or with the outside radius R_0

$t(R_0) = \frac{P_0 \cdot R_0}{S \cdot E + 0.4 \cdot P_0} = \frac{24.55\ \text{bar} \cdot 1951\ \text{mm}}{138\ \text{N/mm}^2 \cdot 1 + 0.4 \cdot 24.55\ \text{bar}} = 34.46\ \text{mm}$ App. 1-1 (1)

$P(R_0) = \frac{S \cdot E \cdot t_0}{R_0 - 0.4 \cdot t_0} = \frac{138\ \text{N/mm}^2 \cdot 1 \cdot 39.69\ \text{mm}}{1951\ \text{mm} - 0.4 \cdot 39.69\ \text{mm}} = 2.83\ \text{MPa}$ App. 1-1 (1)

$\text{Log}(x) = \text{Ln}(x)$

Longitudinal Stress (Circumferential Joints)

$t_{long} = \frac{P_0 \cdot R}{2 \cdot S \cdot E_c + 0.4 \cdot P_0} = \frac{24.55\ \text{bar} \cdot 1911\ \text{mm}}{2 \cdot 138\ \text{N/mm}^2 \cdot E_c + 0.4 \cdot 24.55\ \text{bar}} = t_{long}$ UG-27 (2)

$P_{long} = \frac{2 \cdot S \cdot E_c \cdot t_0}{R - 0.4 \cdot t_0} = \frac{2 \cdot 138\ \text{N/mm}^2 \cdot E_c \cdot 39.69\ \text{mm}}{1911\ \text{mm} - 0.4 \cdot 39.69\ \text{mm}} = P_{long}$ UG-27 (2)

E 4.5.1 - Openings in shells and heads according to ASME BPVC VIII UG-37, 2017 Edition

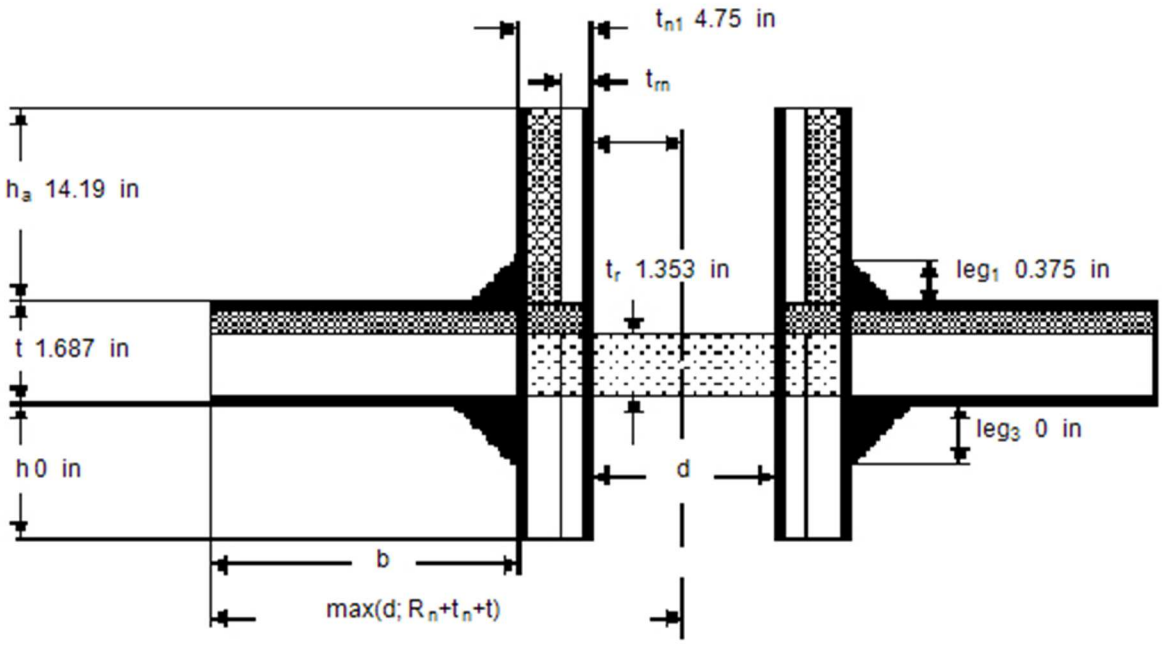
Protruding nozzle without reinforcement

Design pressure	p_D	356	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	***356***	psi
Calculation temperature	T_0	*300*	°F
Factor (1=internal pressure; 2=external pressure)	Γ	1	

Shell

Straight cross section (=Y), as cylinders acc. UG-36(b)(1) and flat heads acc. UG-39(b)(1) or circular cross section (=N) as spheres	Cyl	Y	(N=No)
Outside diameter	D_a	*153.6*	in
Nominal thickness without allowances	t	1.687	in
Required thickness (acc. UG27/32)	t_r	*1.353*	in
Available shell length for reinforcement	b_a	50	in
Joint efficiency factor	E_1	1	
Material *K02700-SA-516-70-Class:-Size:*			
Material strength	K	20015	psi
Safety factor	S	1	
Allowable stress value	S_v	***20015***	psi
Wall thickness allowance	c_{1s}	*0*	in
Corrosion allowance	c_{2s}	*0.125*	in

Nozzle Nº 1



Access opening		No	
Outside diameter	d_a	25.5	in
Joint efficiency factor	E_n	1	
Material K02700-SA-516-70-Class:-Size:			
Material strength	K_n	20015	psi
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Safety factor	S	1	
Allowable stress K_n/S	S_n	**20015**	psi
Nominal thickness with allowances	t_{n1}	4.75	in
Actual wall thickness with allowances acc. Table UG-45	t_{b3}	**0.4533**	in
Nominal inside diameter = da-2*t2	d_{iN}	**16**	in
Inside diameter, corroded = d_a-2·t_n	d	**16.25**	in
External projection	h_a	14.19	in
Internal projection	h	0	in
Angle between the shell axis and the sectional plane through the opening center	Θ	0	°
Nominal thickness without allowances	t_n	**4.625**	in
Required nozzle neck thickness per UG-27	t_a	**0.2711**	in
Required shell wall thickness where the nozzle neck attaches to the vessel (acc.UG27) with joint efficiency E=1.0	t_{b1}	**1.476**	in
Required nozzle neck thickness per UG-45	t_{UG-45}	**0.4533**	in
Fillet weld nozzle / shell outside	leg_1	0.375	in
Fillet weld nozzle / shell inside	leg_3	0	in
Groove weld nozzle / shell (≤t)	leg_4	0	in

Calculation according to		**UG-40**		**App.1-7**	
Correction factor (Fig.UG-37, int. pres.)	F	**1**			
Reserve of shell	$(E_1 \cdot t - F \cdot t_r)$	**0.3346**	in		
Limit length of vessel acc. to UG-40(b)	b	**8.125**	in		in
Limit length of nozzle outside, UG40(c)	h'_a	**4.219**	in	**4.219**	in
Limit length of nozzle inside,Fig.UG37	h'	**0**	in	0	
Minimum required thickness of nozzle	t_{rn}	**0.1461**	in	**0.1461**	in
Required area for internal pressure	A	**14183**	mm²		in²
Area of shell reserve	A_1	**5.438**	in²		mm²
Area of reinforcement (A_2 to A_5)	A_V	**24472**	mm²		mm²
Total available area ∑A	A_{avl}	**27980**	mm²		mm²
Required area A/Γ	A_{req}	**14183**	mm²		mm²
Utilization	A_{req}/A_{avl}	**50.69**	%		%
Allowable pressure (approx.: p_D/utilization)		**702.3**	psi		psi
Save values as adjacent nozzle (1...9)		(1...9)			

Weld loads according to UG-41

W	= $[A-A_1+2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t-F \cdot t_r)] \cdot S_v$	=	**1748756**	N
W_1-1	= $[A_2+A_{41}] \cdot S_v$	=	**3377125**	N
W_2-2	= $[A_2+A_3+A_41+A_{43}+2 \cdot t \cdot t_n \cdot f_{r1}] \cdot S_v$	=	**4766860**	N

Strength of nozzle wall, fillet and groove welds

Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot leg_1 \cdot 0.49 \cdot \min(S_v;S_n)$	=	**655292**	N
Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot leg_3 \cdot 0.49 \cdot \min(S_v;S_n)$	=	**0**	N
Groove shell /nozzle	$\pi/2 \cdot d_a \cdot leg_4 \cdot 0.74 \cdot \min(S_v;S_n)$	=	**0**	N
Nozzle wall	$\pi/2 \cdot d_m \cdot t_n \cdot 0.70 \cdot S_n$	=	**9451564**	N

Comparison of weld loads on path 1-1 and 2-2

1-1	**655292** N	+	**9451564** N	=	**1.011e+7**	N		
				≥	**1748756**	N		
2-2	**655292** N	+	**0** N	+	**0** N	=	**8520546**	N
				≥	**1748756**	N		

Equations according to UG-40 and App.1-7

$$b = Max\left\{\begin{array}{l}\frac{d}{2}\\ t_n + t\end{array}\right. = Max\left\{\begin{array}{l}\frac{d}{2}\\ t_n + t\end{array}\right. = 206.4 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = Max\left\{\begin{array}{l}\frac{3 \cdot d/2}{4}\\ t_n + t\end{array}\right.$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$

App.1-7(a)(1)

$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) =$$

$$412.8 \text{ mm} \cdot 34.36 \text{ mm} \cdot 1 + 2 \cdot 117.5 \text{ mm} \cdot 34.36 \text{ mm} \cdot 1 \cdot (1 - 1) = 14183 \text{ mm}^2$$

Fig. UG-37.1

Available shell thickness with allowances $t+c_{1s}+c_{2s}$	t_s	***1.812***	in
Required shell thickness with allowances t_r+...	t_{sr}	**1.478**	in
Required nozzle thickness with allowances	t_{rn+}	**0.2711**	in

Areas according to UG-40

$$h'_a = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h_a \end{Bmatrix} = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h_a \end{Bmatrix} = 107.2\ \text{mm}$$

$$h' = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h \end{Bmatrix} = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h \end{Bmatrix} = 0\ \text{mm}$$

$$t_{rm} = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06\cdot p_0)} = 24.55\ \text{bar} \cdot \frac{\frac{412.8\ \text{mm}}{20}}{(138\ \text{N/mm}^2 - 0.06\cdot 24.55\ \text{bar})} = 3.71\ \text{mm}$$ (internal pressure)

$$A_1 = Max\begin{Bmatrix} d\cdot(E_1\cdot t - F\cdot t_r) - 2\cdot t_n\cdot(E_1\cdot t - F\cdot t_r)\cdot(1-f_{r1}) \\ 2\cdot(t+t_n)\cdot(E_1\cdot t - F\cdot t_r) - 2\cdot t_n\cdot(E_1\cdot t - F\cdot t_r)\cdot(1-f_{r1}) \end{Bmatrix} =$$

$$Max\begin{Bmatrix} 412.8\ \text{mm}\cdot 8.499\ \text{mm} - 2\cdot 117.5\ \text{mm}\cdot 8.499\ \text{mm}\cdot(1-1) \\ 2\cdot(42.86\ \text{mm}+117.5\ \text{mm})\cdot 8.499\ \text{mm} - 2\cdot 117.5\ \text{mm}\cdot 8.499\ \text{mm}\cdot(1-1) \end{Bmatrix} = 3508\ \text{mm}^2$$

$$A_2 = 2\cdot(t_n - t_{rn})\cdot f_{r2}\cdot h'_a = 2\cdot(117.5\ \text{mm} - 3.71\ \text{mm})\cdot 1\cdot 107.2\ \text{mm} = 24381\ \text{mm}^2$$

$$A_3 = 2\cdot(t_n - c_2)\cdot f_{r2}\cdot h' = 2\cdot(117.5\ \text{mm} - 3.175\ \text{mm})\cdot 1\cdot 0\ \text{mm} = 0\ \text{mm}^2$$

$$A_{41} = (leg_1)^2\cdot f_{r2} = (9.525\ \text{mm})^2\cdot 1 = 90.73\ \text{mm}^2$$

$$A_{43} = (leg_3)^2\cdot f_{r2} = (0\ \text{mm})^2\cdot 1 = 0\ \text{mm}^2$$

$$A_V = A_2 + A_3 + A_{41} + A_{43} = A_2 + A_3 + A_{41} + A_{43} = 24472\ \text{mm}^2$$

App.1-7 is additionally required acc. to UG-36(b) if

D_a	*3902* ≤ 1520mm (60in.):	d_a	647.7 > Min [	*3902*/2; 508mm (20in.)]
D_a	*3902* > 1520mm (60in.):	d_a	647.7 > Min [	*3902*/3; 1000mm (40in.)]

Additional rules for cylindr. shells, App.1-7(b) not required

Total available area		A_{avl}	mm²
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{mn}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	mm^4
Material area acc. to Fig.1-7-1		A_s	mm²
Support length nozzle	$Min[h_a; t_e + (R_{nm}\cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$Min[b_a; (R_m\cdot t_e)^{0.5}]$	l_m	in

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R =$ [redacted] $> 1524 mm (60 in.)$

(b) $2 \cdot R_n =$ [redacted] > 1016 mm (40 in.) and $2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t} =$ [redacted]

(c) $\frac{R_n}{R} =$ [redacted] $=$ [redacted] ≤ 0.7

Membrane stress Sm acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{[R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})]}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2}$$

$$l_m = Min \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = Min \left\{ \begin{array}{l} h_a \\ t_e + \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. to App.1-7(b)(4)

$S_m = \leq S$

Bending stress Sb acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{42.86 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$

E 4.5.2 Step5 F=1 - Openings in shells and heads according to ASME BPVC VIII UG-37, 2017 Edition

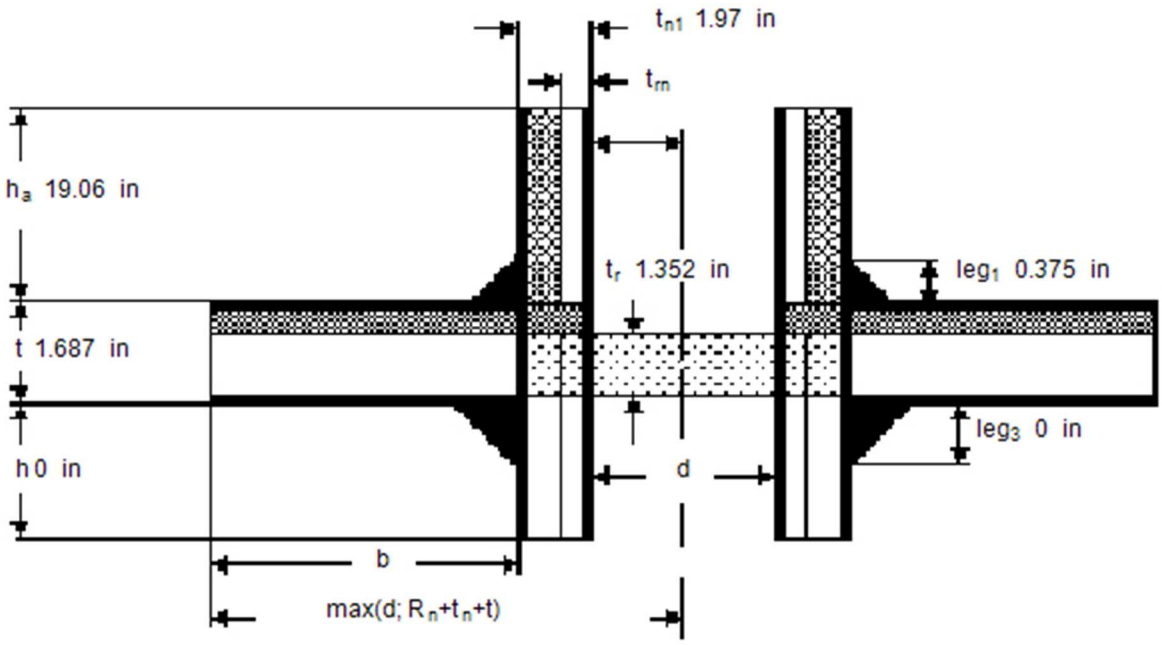
Protruding nozzle without reinforcement

Design pressure	p_D	356	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	***356***	psi
Calculation temperature	T_0	*300*	°F
Factor (1=internal pressure; 2=external pressure)	Γ	1	

Shell

Straight cross section (=Y), as cylinders acc. UG-36(b)(1) and flat heads acc. UG-39(b)(1) or circular cross section (=N) as spheres	Cyl	Y	(N=No)
Outside diameter	D_a	*153.6*	in
Nominal thickness without allowances	t	1.687	in
Required thickness (acc. UG27/32)	t_r	1.352	in
Available shell length for reinforcement	b_a	60	in
Joint efficiency factor	E_1	1	
Material *K02700-SA-516-70-Class:-Size:*			
Material strength	K	20015	psi
Safety factor	S	1	
Allowable stress value	S_v	***20015***	psi
Wall thickness allowance	c_{1s}	*0*	in
Corrosion allowance	c_{2s}	*0.125*	in

Nozzle Nº 1



Access opening		No	
Outside diameter	d_a	11.56	in
Joint efficiency factor	E_n	1	
Material K02700-SA-516-70-Class:-Size:			
Material strength	K_n	20015	psi
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Safety factor	S	1	
Allowable stress K_n/S	S_n	**20015**	psi
Nominal thickness with allowances	t_{n1}	1.97	in
Actual wall thickness with allowances acc. Table UG-45	t_{b3}	**0.4533**	in
Nominal inside diameter = da-2*t2	d_{iN}	**7.62**	in
Inside diameter, corroded = d_a-2·t_n	d	**7.87**	in
External projection	h_a	19.06	in
Internal projection	h	0	in
Angle between the shell axis and the sectional plane through the opening center	Θ	0	°
Nominal thickness without allowances	t_n	**1.845**	in
Required nozzle neck thickness per UG-27	t_a	**0.1957**	in
Required shell wall thickness where the nozzle neck attaches to the vessel (acc.UG27) with joint efficiency E=1.0	t_{b1}	**1.475**	in
Required nozzle neck thickness per UG-45	t_{UG-45}	**0.4533**	in
Fillet weld nozzle / shell outside	leg_1	0.375	in
Fillet weld nozzle / shell inside	leg_3	0	in
Groove weld nozzle / shell (≤t)	leg_4	0	in

Calculation according to		**UG-40**		**App.1-7**	
Correction factor (Fig.UG-37, int. pres.)	F	**1**			
Reserve of shell	$(E_1 \cdot t - F \cdot t_r)$	**0.3358**	in		
Limit length of vessel acc. to UG-40(b)	b	**3.935**	in		in
Limit length of nozzle outside, UG40(c)	h'_a	**4.219**	in	**4.219**	in
Limit length of nozzle inside,Fig.UG37	h'	**0**	in	0	
Minimum required thickness of nozzle	t_{rn}	**0.07075**	in	**0.07075**	in
Required area for internal pressure	A	**6863**	mm^2		in^2
Area of shell reserve	A_1	**2.643**	in^2		mm^2
Area of reinforcement (A_2 to A_5)	A_V	**9749**	mm^2		mm^2
Total available area ∑A	A_{avl}	**11454**	mm^2		mm^2
Required area A/Γ	A_{req}	**6863**	mm^2		mm^2
Utilization	A_{req}/A_{avl}	**59.92**	%		%
Allowable pressure (approx.: p_D/utilization)		**594.1**	psi		psi
Save values as adjacent nozzle (1...9)		(1...9)			

Weld loads according to UG-41

W	= $[A-A_1+2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	=	**822143**	N
W_1-1	= $[A_2+A_{41}] \cdot S_v$	=	**1345355**	N
W_2-2	= $[A_2+A_3+A_41+A_{43}+2 \cdot t \cdot t_n \cdot f_{r1}] \cdot S_v$	=	**1899746**	N

Strength of nozzle wall, fillet and groove welds

Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot leg_1 \cdot 0.49 \cdot \min(S_v;S_n)$	=	**297066**	N
Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot leg_3 \cdot 0.49 \cdot \min(S_v;S_n)$	=	**0**	N
Groove shell /nozzle	$\pi/2 \cdot d_a \cdot leg_4 \cdot 0.74 \cdot \min(S_v;S_n)$	=	**0**	N
Nozzle wall	$\pi/2 \cdot d_m \cdot t_n \cdot 0.70 \cdot S_n$	=	**1754707**	N

Comparison of weld loads on path 1-1 and 2-2

1-1	**297066** N	+	**1754707** N	=	**2051773**	N		
				≥	**822143**	N		
2-2	**297066** N	+	**0** N	+	**0** N	=	**297066**	N
				≥	**822143**	N		

Equations according to UG-40 and App.1-7

$$b = Max\left\{\begin{array}{l}\frac{d}{2} \\ t_n + t\end{array}\right. = Max\left\{\begin{array}{l}\frac{d}{2} \\ t_n + t\end{array}\right. = 99.95 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = Max\left\{\begin{array}{l}\frac{3 \cdot d/2}{4} \\ t_n + t\end{array}\right.$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$

App.1-7(a)(1)

$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) =$$

$$199.9 \text{ mm} \cdot 34.33 \text{ mm} \cdot 1 + 2 \cdot 46.86 \text{ mm} \cdot 34.33 \text{ mm} \cdot 1 \cdot (1 - 1) = 6863 \text{ mm}^2$$

Fig. UG-37.1

Available shell thickness with allowances $t+c_{1s}+c_{2s}$	t_s	***1.812***	in
Required shell thickness with allowances t_r+...	t_{sr}	**1.477**	in
Required nozzle thickness with allowances	t_{rn+}	**0.1957**	in

Areas according to UG-40

$$h'_a = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h_a \end{Bmatrix} = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h_a \end{Bmatrix} = 107.2\ \text{mm}$$

$$h' = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h \end{Bmatrix} = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h \end{Bmatrix} = 0\ \text{mm}$$

$$t_{rm} = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06\cdot p_0)} = 24.55\ \text{bar} \cdot \frac{\frac{199.9\ \text{mm}}{20}}{(138\ \text{N/mm}^2 - 0.06\cdot 24.55\ \text{bar})} = 1.797\ \text{mm}$$ (internal pressure)

$$A_1 = Max\begin{Bmatrix} d\cdot(E_1\cdot t - F\cdot t_r) - 2\cdot t_n\cdot(E_1\cdot t - F\cdot t_r)\cdot(1-f_{r1}) \\ 2\cdot(t+t_n)\cdot(E_1\cdot t - F\cdot t_r) - 2\cdot t_n\cdot(E_1\cdot t - F\cdot t_r)\cdot(1-f_{r1}) \end{Bmatrix} =$$

$$Max\begin{Bmatrix} 199.9\ \text{mm}\cdot 8.529\ \text{mm} - 2\cdot 46.86\ \text{mm}\cdot 8.529\ \text{mm}\cdot(1-1) \\ 2\cdot(42.86\ \text{mm}+46.86\ \text{mm})\cdot 8.529\ \text{mm} - 2\cdot 46.86\ \text{mm}\cdot 8.529\ \text{mm}\cdot(1-1) \end{Bmatrix} = 1705\ \text{mm}^2$$

$$A_2 = 2\cdot(t_n - t_{rn})\cdot f_{r2}\cdot h'_a = 2\cdot(46.86\ \text{mm} - 1.797\ \text{mm})\cdot 1\cdot 107.2\ \text{mm} = 9658\ \text{mm}^2$$

$$A_3 = 2\cdot(t_n - c_2)\cdot f_{r2}\cdot h' = 2\cdot(46.86\ \text{mm} - 3.175\ \text{mm})\cdot 1\cdot 0\ \text{mm} = 0\ \text{mm}^2$$

$$A_{41} = (leg_1)^2\cdot f_{r2} = (9.525\ \text{mm})^2\cdot 1 = 90.73\ \text{mm}^2$$

$$A_{43} = (leg_3)^2\cdot f_{r2} = (0\ \text{mm})^2\cdot 1 = 0\ \text{mm}^2$$

$$A_V = A_2 + A_3 + A_{41} + A_{43} = A_2 + A_3 + A_{41} + A_{43} = 9749\ \text{mm}^2$$

App.1-7 is additionally required acc. to UG-36(b) if

D_a	*3901* ≤ 1520mm (60in.):	d_a	293.6	> Min [	*3901*/2; 508mm (20in.)]
D_a	*3901* > 1520mm (60in.):	d_a	293.6	> Min [	*3901*/3; 1000mm (40in.)]

Additional rules for cylindr. shells, App.1-7(b) not required

Total available area		A_{avl}	mm²
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{mn}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	mm^4
Material area acc. to Fig.1-7-1		A_s	mm²
Support length nozzle	$Min[h_a; t_e + (R_{nm}\cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$Min[b_a; (R_m\cdot t_e)^{0.5}]$	l_m	in

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R =$ [redacted] $> 1524 mm (60 in.)$

(b) $2 \cdot R_n =$ [redacted] > 1016 mm (40 in.) and $2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t} =$ [redacted]

(c) $\frac{R_n}{R} =$ [redacted] $=$ [redacted] ≤ 0.7

Membrane stress Sm acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{[R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})]}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2}$$

$$l_m = Min \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = Min \left\{ \begin{array}{l} h_a \\ t_e + \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. to App.1-7(b)(4)

$S_m = \leq S$

Bending stress Sb acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{42.86 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$

E 4.5.3 - Openings in shells and heads according to ASME BPVC VIII UG-37, 2017 Edition

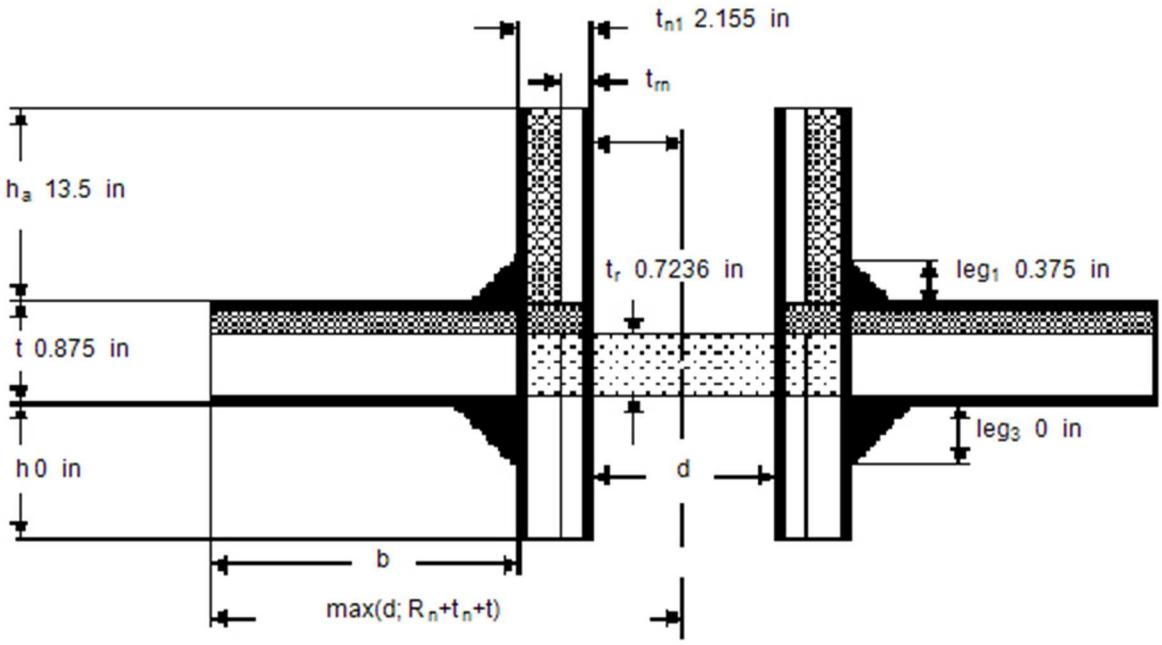
Protruding nozzle without reinforcement

Design pressure	p_D	356	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	***356***	psi
Calculation temperature	T_0	*300*	°F
Factor (1=internal pressure; 2=external pressure)	Γ	1	

Shell

Straight cross section (=Y), as cylinders acc. UG-36(b)(1) and flat heads acc. UG-39(b)(1) or circular cross section (=N) as spheres	Cyl	N	(N=No)
Outside diameter	D_a	*92*	in
Nominal thickness without allowances	t	0.875	in
Required thickness (acc. UG27/32)	t_r	0.7236	in
Available shell length for reinforcement	b_a	40	in
Joint efficiency factor	E_1	1	
Material *K02700-SA-516-70-Class:-Size:*			
Material strength	K	20015	psi
Safety factor	S	1	
Allowable stress value	S_v	***20015***	psi
Wall thickness allowance	c_{1s}	*0*	in
Corrosion allowance	c_{2s}	*0.125*	in

Nozzle Nº 1



Access opening		No	
Outside diameter	d_a	15.94	in
Joint efficiency factor	E_n	1	
Material K02700-SA-516-70-Class:-Size:			
Material strength	K_n	20015	psi
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.03937	in
Safety factor	S	1	
Allowable stress K_n/S	S_n	**20015**	psi
Nominal thickness with allowances	t_{n1}	2.155	in
Actual wall thickness with allowances acc. Table UG-45	t_{b3}	**0.3677**	in
Nominal inside diameter = da-2*t2	d_{iN}	**11.63**	in
Inside diameter, corroded = d_a-2·t_n	d	**11.71**	in
External projection	h_a	13.5	in
Internal projection	h	0	in
Angle between the shell axis and the sectional plane through the opening center	Θ	0	°
Nominal thickness without allowances	t_n	**2.116**	in
Required nozzle neck thickness per UG-27	t_a	**0.1446**	in
Required shell wall thickness where the nozzle neck attaches to the vessel (acc.UG27) with joint efficiency E=1.0	t_{b1}	**0.527**	in
Required nozzle neck thickness per UG-45	t_{UG-45}	**0.3677**	in
Fillet weld nozzle / shell outside	leg_1	0.375	in
Fillet weld nozzle / shell inside	leg_3	0	in
Groove weld nozzle / shell (≤t)	leg_4	0	in

Calculation according to		**UG-40**		**App.1-7**	
Correction factor (Fig.UG-37, int. pres.)	F	**1**			
Reserve of shell	$(E_1 \cdot t - F \cdot t_r)$	**0.1514**	in		
Limit length of vessel acc. to UG-40(b)	b	**5.854**	in		in
Limit length of nozzle outside, UG40(c)	h'_a	**2.188**	in	**2.188**	in
Limit length of nozzle inside,Fig.UG37	h'	**0**	in	0	
Minimum required thickness of nozzle	t_{rn}	**0.1053**	in	**0.1053**	in
Required area for internal pressure	A	**5466**	mm²		in²
Area of shell reserve	A_1	**1.773**	in²		mm²
Area of reinforcement (A_2 to A_5)	A_V	**5765**	mm²		mm²
Total available area ∑A	A_{avl}	**6909**	mm²		mm²
Required area A/Γ	A_{req}	**5466**	mm²		mm²
Utilization	A_{req}/A_{avl}	**79.12**	%		%
Allowable pressure (approx.: p_D/utilization)		**450**	psi		psi
Save values as adjacent nozzle (1...9)		(1...9)			

Weld loads according to UG-41

W	$= [A-A_1+2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t-F \cdot t_r)] \cdot S_v$	=	**653527**	N
W_1-1	$= [A_2+A_{41}] \cdot S_v$	=	**795593**	N
W_2-2	$= [A_2+A_3+A_41+A_{43}+2 \cdot t \cdot t_n \cdot f_{r1}] \cdot S_v$	=	**1125221**	N

Strength of nozzle wall, fillet and groove welds

Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot leg_1 \cdot 0.49 \cdot \min(S_v;S_n)$	=	**409622**	N
Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot leg_3 \cdot 0.49 \cdot \min(S_v;S_n)$	=	**0**	N
Groove shell /nozzle	$\pi/2 \cdot d_a \cdot leg_4 \cdot 0.74 \cdot \min(S_v;S_n)$	=	**0**	N
Nozzle wall	$\pi/2 \cdot d_m \cdot t_n \cdot 0.70 \cdot S_n$	=	**2863192**	N

Comparison of weld loads on path 1-1 and 2-2

1-1	**409622** N	+	**2863192** N	=	**3272814** N			
				≥	**653527** N			
2-2	**409622** N	+	**0** N	+	**0** N	=	**409622** N	
				≥	**653527** N			

Equations according to UG-40 and App.1-7

$$b = Max\left\{\begin{array}{l}\frac{d}{2} \\ t_n + t\end{array}\right. = Max\left\{\begin{array}{l}\frac{d}{2} \\ t_n + t\end{array}\right. = 148.7 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = Max\left\{\begin{array}{l}\frac{3 \cdot d/2}{4} \\ t_n + t\end{array}\right.$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$

App.1-7(a)(1)

$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) =$$

$$297.4 \text{ mm} \cdot 18.38 \text{ mm} \cdot 1 + 2 \cdot 53.74 \text{ mm} \cdot 18.38 \text{ mm} \cdot 1 \cdot (1-1) = 5466 \text{ mm}^2$$

Fig. UG-37.1

Available shell thickness with allowances $t+c_{1s}+c_{2s}$	t_s	***1***	in
Required shell thickness with allowances t_r+...	t_{sr}	**0.8486**	in
Required nozzle thickness with allowances	t_{rn+}	**0.1446**	in

Areas according to UG-40

$$h'_a = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h_a \end{Bmatrix} = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h_a \end{Bmatrix} = 55.56\ \text{mm}$$

$$h' = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h \end{Bmatrix} = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h \end{Bmatrix} = 0\ \text{mm}$$

$$t_{rm} = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06\cdot p_0)} = 24.55\ \text{bar} \cdot \frac{\frac{297.4\ \text{mm}}{20}}{(138\ \text{N/mm}^2 - 0.06\cdot 24.55\ \text{bar})} = 2.673\ \text{mm} \qquad \text{(internal pressure)}$$

$$A_1 = Max\begin{Bmatrix} d\cdot(E_1\cdot t - F\cdot t_r) - 2\cdot t_n\cdot(E_1\cdot t - F\cdot t_r)\cdot(1-f_{r1}) \\ 2\cdot(t+t_n)\cdot(E_1\cdot t - F\cdot t_r) - 2\cdot t_n\cdot(E_1\cdot t - F\cdot t_r)\cdot(1-f_{r1}) \end{Bmatrix} =$$

$$Max\begin{Bmatrix} 297.4\ \text{mm}\cdot 3.846\ \text{mm} - 2\cdot 53.74\ \text{mm}\cdot 3.846\ \text{mm}\cdot(1-1) \\ 2\cdot(22.23\ \text{mm}+53.74\ \text{mm})\cdot 3.846\ \text{mm} - 2\cdot 53.74\ \text{mm}\cdot 3.846\ \text{mm}\cdot(1-1) \end{Bmatrix} = 1144\ \text{mm}^2$$

$$A_2 = 2\cdot(t_n - t_{rn})\cdot f_{r2}\cdot h'_a = 2\cdot(53.74\ \text{mm} - 2.673\ \text{mm})\cdot 1\cdot 55.56\ \text{mm} = 5674\ \text{mm}^2$$

$$A_3 = 2\cdot(t_n - c_2)\cdot f_{r2}\cdot h' = 2\cdot(53.74\ \text{mm} - 1\ \text{mm})\cdot 1\cdot 0\ \text{mm} = 0\ \text{mm}^2$$

$$A_{41} = (leg_1)^2\cdot f_{r2} = (9.525\ \text{mm})^2\cdot 1 = 90.73\ \text{mm}^2$$

$$A_{43} = (leg_3)^2\cdot f_{r2} = (0\ \text{mm})^2\cdot 1 = 0\ \text{mm}^2$$

$$A_V = A_2 + A_3 + A_{41} + A_{43} = A_2 + A_3 + A_{41} + A_{43} = 5765\ \text{mm}^2$$

App.1-7 is additionally required acc. to UG-36(b) if

D_a	*2337* ≤ 1520mm (60in.):	d_a	404.9 > Min [	*2337*/2; 508mm (20in.)]
D_a	*2337* > 1520mm (60in.):	d_a	404.9 > Min [	*2337*/3; 1000mm (40in.)]

Additional rules for cylindr. shells, App.1-7(b) not required

Total available area		A_{avl}	mm²
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{mn}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	mm^4
Material area acc. to Fig.1-7-1		A_s	mm²
Support length nozzle	$Min[h_a; t_e + (R_{nm}\cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$Min[b_a; (R_m\cdot t_e)^{0.5}]$	l_m	in

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R =$ [redacted] $> 1524 mm (60 in.)$

(b) $2 \cdot R_n =$ [redacted] > 1016 mm (40 in.) and $2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t} =$ [redacted]

(c) $\frac{R_n}{R} =$ [redacted] $=$ [redacted] ≤ 0.7

Membrane stress Sm acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{[R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})]}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2}$$

$$l_m = Min \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = Min \left\{ \begin{array}{l} h_a \\ t_e + \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. to App.1-7(b)(4)

$S_m = \leq S$

Bending stress Sb acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{22.23 \text{ mm}}{2} = a$$

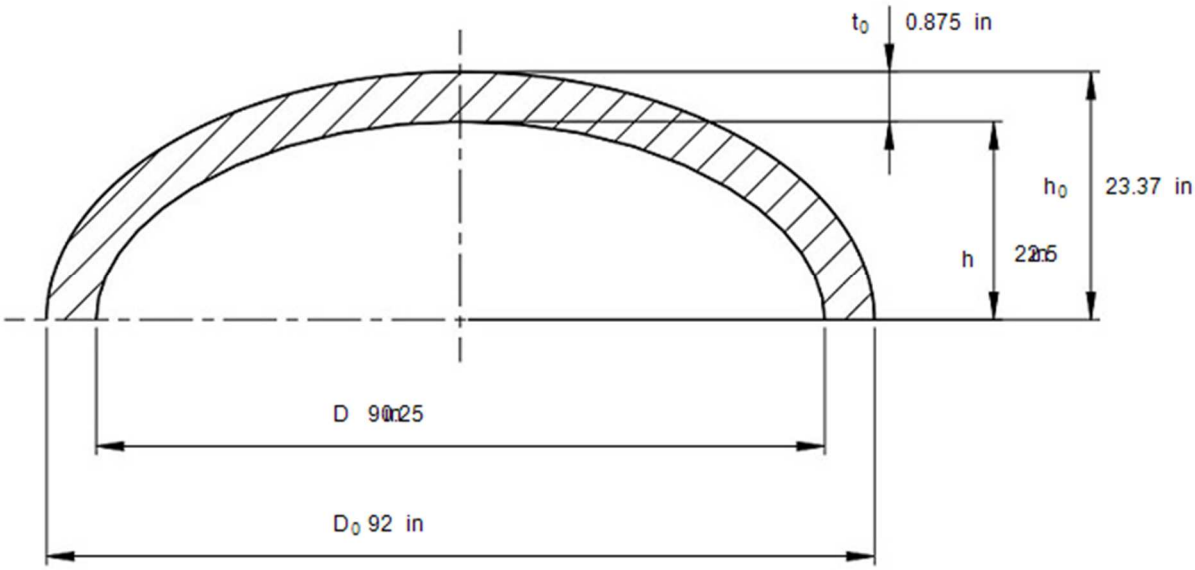
$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$

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

Ellipsoidal heads acc. UG-32(c) and Appendix 1-4(f)

Design pressure	p_D	356	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	**24.55**	bar
Calculation temperature	T_0	300	°F
Final wall thickness	t_e	1	in
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.125	in
Effective thickness witout allowances	t_0	**0.875**	in



Outside diameter of cylindrical shell		D_0	**92**	in
Inside diameter of cylindrical shell	(= D_0-2t_0)	D	90.25	in
Outer height of head		h_0	**23.37**	in
Inside depth of head	(minor semi-axis= h_0-t_0)	h	22.5	in
Weld joint efficiency		E	1	

Material data

Material	K02700-SA-516-70-Class:-Size:		
Elasticity modulus	E_T	2.829e+7	psi
Elastic limit	S_y	33668	psi
Reduce allowable*) stress for R_{m20} > 485 MPa?		Yes	(Yes/No)
Tensile strength at 20°C	R_{m20}	70343	psi
Allowable stress			
at working temperature acc. ASME-table	S_T	20015	psi
at 20°C	S_{20}	20015	psi
acc. UG-32(e) or App. 1-4(c)	S	**20015**	psi

*) According to App. 1-4(c), the allowable stress must be reduced to 138 * S_T /S_{20} (=20 ksi*...) for R_{m20} > 485 MPa (70 ksi).

Results

Ratio	D/2h	**2**	
Factor	K	**1**	
Factor K1 acc. Table UG-37	K_1	**0.9**	
Required thickness	t	**0.804**	in
incl. allowances (t_e 1 in ≥t+)	t+	**0.929**	in
Allowable excess pressure incl. hydrostatic Head	P	**387.4**	psi
Allowable excess pressure without hydrostatic Head	MAWP	**387.4**	psi

Required thickness for openings acc. to UG-37(a) in nomenclature for t_r

Using UG-32 with E=1	t(E=1)	**0.804**	in
Section (c) in the centre circle (< 0.8·D)	t_1(E=1)	***0.7236***	in
Equivalent spherical diameter $2 \cdot K_1 \cdot D_0$	D_s	**167.6**	in

Geometrical conditions

valid

Strength

Wall thickness acceptable

Allowable unreinforced opening diameter dA for welded, brazed, and flued connections acc. UG 36(c)3

$d_A \leq 89$ mm (3.5 in.) for t ≤10 mm (3/8 in.)
$d_A \leq 60$ mm (2 3/8 in.) for t > 10 mm (3/8 in.)

Remark

Equations according to UG-32

$$t = \frac{P_0 \cdot D \cdot K}{2 \cdot S \cdot E - 0.2 \cdot P_0} = \frac{24.55\ \text{bar} \cdot 2292\ \text{mm} \cdot 1}{2 \cdot 138\ \text{N/mm}^2 \cdot 1 - 0.2 \cdot 24.55\ \text{bar}} = 20.42\ \text{mm}$$

$$P = \frac{2 \cdot S \cdot E \cdot t_0}{K \cdot D + 0.2 \cdot t_0} = \frac{2 \cdot 138\ \text{N/mm}^2 \cdot 1 \cdot 22.23\ \text{mm}}{1 \cdot 2292\ \text{mm} + 0.2 \cdot 22.23\ \text{mm}} = 2.671\ \text{MPa}$$

E4.5.5 - Openings in shells and heads according to ASME BPVC VIII UG-37, 2017 Edition

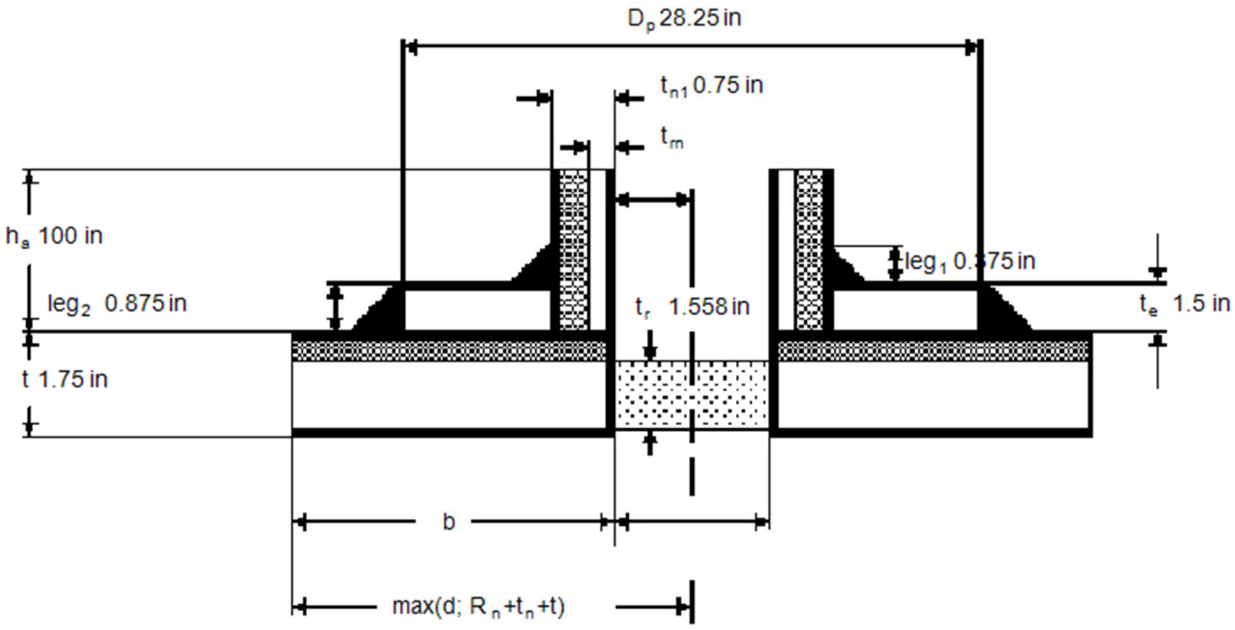
Set-on nozzle with reinforcement

Design pressure	p_D		500	psi
Hydrostatic head	D_p		0	psi
Calculation pressure	p_0		***500***	psi
Calculation temperature	T_0		*400*	°F
Factor (1=internal pressure; 2=external pressure)	Γ		1	

Shell

Straight cross section (=Y), as cylinders acc. UG-36(b)(1) and flat heads acc. UG-39(b)(1) or circular cross section (=N) as spheres	Cyl	Y		(N=No)
Outside diameter	D_a		*87*	in
Nominal thickness without allowances	t		1.75	in
Required thickness (acc. UG27/32)	t_r		1.558	in
Available shell length for reinforcment	b_a		50	in
Joint efficiency factor	E_1		1	
Material				
Material strength	K			psi
Safety factor	S			
Allowable stress value K/S	S_v		*13700*	psi
Wall thickness allowance	c_{1s}		*0*	in
Corrosion allowance	c_{2s}		*0.25*	in

Nozzle Nº 1



Access opening		No	
Outside diameter	d_a	16	in
Joint efficiency factor	E_n	1	
Material			
Material strength	K_n	**13700**	psi
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.25	in
Safety factor	S	1	
Allowable stress value K_n/S	S_n	13700	psi
Nominal thickness with allowances	t_{n1}	0.75	in
Actual wall thickness with allowances acc. Table UG-45	t_{b3}	**0.5783**	in
Nominal inside diameter = da-2*t2	d_{iN}	**14.5**	in
Inside diameter, corroded = d_a-2·t_n	d	**15**	in
External projection	h_a	100	in
Angle between the shell axis and the sectional plane through the opening center	Θ	0	°
Nominal thickness without allowances	t_n	**0.5**	in
Required nozzle neck thickness per UG-27	t_a	**0.5299**	in
Required shell wall thickness where the nozzle neck attaches to the vessel (acc.UG27) with joint efficiency E=1.0	t_{b1}	**1.808**	in
Required nozzle neck thickness per UG-45	t_{UG-45}	**0.5783**	in

Reinforcing element

Thickness	t_e	1.5	in
Outside diameter	D_p	28.25	in
Material			
Material strength	K_p		psi
Safety factor	S		
Allowable stress	S_p	1987007	psi
Fillet nozzle/ reinforcement outside	leg_1	0.375	in
Fillet of reinforcement / shell outside	leg_2	0.875	in
Groove nozzle / shell (≤tn)	leg_4	0.5	in
Groove reinforcement / nozzle(≤te)	leg_5	0.5	in

Calculation according to		**UG-40**		**App.1-7**	
Correction factor (Fig.UG-37, int. pres.)	F	**1**			
Reserve of shell	$(E_1 \cdot t - F \cdot t_r)$	**0.1922**	in		
Limit length of vessel acc. to UG-40(b)	b	**7.5**	in		in
Limit length of nozzle outside, UG40(c)	h'_a	**2.75**	in	**2.75**	in
Minimum required thickness of nozzle	t_{rn}	**0.2799**	in	**0.2799**	in
Projected Area	A	**15075**	mm²		in²
Area of shell reserve	A_1	**2.883**	in²		mm²
Area of reinforcement (A_2 to A_5)	A_V	**13221**	mm²		mm²
Total available area ∑A	∑A	**15081**	mm²		mm²
Required area A/Γ	A/H	**15075**	mm²		mm²
Utilization	A_{req}/A_{avl}	**99.97**	%		%
Allowable pressure (Approx.: pD/utilization)		**500.2**	psi		psi
Save values as adjacent nozzle (1..9)		(1..9)			

Weld loads according to UG-41

W	= $[A-A_1+2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	=	**1248316**	N
W_1-1	= $[A_2+A_5+A_{41}+A_{42}] \cdot S_v$	=	**1248808**	N
W_2-2	= $[A_2+A_{41}] \cdot S_v$	=	**82358**	N

Strength of fillet welds

Reinf./nozzle	$\pi/2 \cdot d_a \cdot leg_1 \cdot 0.49 \cdot \min(S_p;S_n)$	**281435**	N
Reinf./shell	$\pi/2 \cdot D_p \cdot leg_2 \cdot 0.49 \cdot \min(S_p;S_v)$	**1159453**	N

Groove weld

Shell /Nozzle	$\pi/2 \cdot d_a \cdot leg_4 \cdot 0.60 \cdot \min(S_v;S_n)$	**445127**	N
Reinf./nozzle	$\pi/2 \cdot d_a \cdot leg_5 \cdot 0.74 \cdot \min(S_p;S_n)$	**566699**	N

Comparison of loads on path 1-1 and 2-2

1-1			**1159453**	N	+	**445127**	N	=	**1604580**	N
							≥		**1248316**	N
2-2	**566699**	N	+	**281435**	N	+	**445127**	N	=	**1293260**	N
							≥		**82358**	N

Equations according to UG-40 and App.1-7

$$b = Max\left\{\begin{array}{l} \frac{d}{2} \\ t_n + t \end{array}\right. = Max\left\{\begin{array}{l} \frac{d}{2} \\ t_n + t \end{array}\right. = 190.5 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = Max\left\{\begin{array}{l} \frac{3 \cdot d/2}{4} \\ t_n + t \end{array}\right.$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot d \cdot t_r \cdot F$$

App.1-7(a)(1)

$$A = d \cdot t_r \cdot F = 381 \text{ mm} \cdot 39.57 \text{ mm} \cdot 1 = 15075 \text{ mm}^2$$

Fig. UG-37.1

Available shell thickness with allowances $t+c_{1s}+c_{2s}$	t_s	***2***	in
Required shell thickness with allowances t_r+...	t_{sr}	**1.808**	in
Required nozzle thickness with allowances	t_{rn+}	**0.5299**	in

Areas according to UG-40

$$h'_a = Min\begin{cases} 2.5 \cdot t \\ 2.5 \cdot t_n + t_e \\ h_a \end{cases} = 69.85 \text{ mm}$$

$$t_{rn} = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06 \cdot p_0)} =$$

(internal pressure)

$$34.47 \text{ bar} \cdot \frac{\frac{381 \text{ mm}}{20}}{(94.46 \text{ N/mm}^2 - 0.06 \cdot 34.47 \text{ bar})} = 7.108 \text{ mm}$$

$$A_1 = Max\begin{cases} d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \end{cases} =$$

$$Max\begin{cases} 381 \text{ mm} \cdot 4.882 \text{ mm} - 2 \cdot 12.7 \text{ mm} \cdot 4.882 \text{ mm} \cdot (1 - f_{r1}) \\ 2 \cdot (44.45 \text{ mm} + 12.7 \text{ mm}) \cdot 4.882 \text{ mm} - 2 \cdot 12.7 \text{ mm} \cdot 4.882 \text{ mm} \cdot (1 - f_{r1}) \end{cases} = 1860 \text{ mm}^2$$

$$A_2 = 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot h'_a = 2 \cdot (12.7 \text{ mm} - 7.108 \text{ mm}) \cdot 1 \cdot 69.85 \text{ mm} = 781.2 \text{ mm}^2$$

$$A_{41} = (leg_1)^2 \cdot f_{r3} = (9.525 \text{ mm})^2 \cdot 1 = 90.73 \text{ mm}^2$$

$$A_{42} = (leg_2)^2 \cdot f_{r4} = (22.23 \text{ mm})^2 \cdot 1 = 494 \text{ mm}^2$$

$$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4} = (717.5 \text{ mm} - 381 \text{ mm} - 2 \cdot 12.7 \text{ mm}) \cdot 38.1 \text{ mm} \cdot 1 = 11855 \text{ mm}^2$$

$$A_V = A_2 + A_{41} + A_{42} + A_5 = A_2 + A_{41} + A_{42} + A_5 = 13221 \text{ mm}^2$$

App.1-7 is additionally required according to UG-36(b), if

D_a	*2210* ≤ 1520mm (60in.):	d_a	406.4	> Min [	*2210*/2; 508mm (20in.)]
D_a	*2210* > 1520mm (60in.):	d_a	406.4	> Min [	*2210*/3; 1000mm (40in.)]

Large cylinder opening acc. Appendix 1-7(b) not required

Total available area		A_{avl}	mm²
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{mn}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	mm^4
Material area acc. to Fig.1-7-1		A_s	mm²
Support length nozzle	$Min[h_a; t_e + (R_{nm} \cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$Min[b_a; (R_m \cdot t_e)^{0.5}]$	l_m	in

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R = > 1524 mm (60 in.)$

(b) $2 \cdot R_n =$ > 1016 mm (40 in.) and $2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t}$

(c) $\frac{R_n}{R} = \frac{\text{[illegible]}}{\text{[illegible]}} = \text{[illegible]} \leq 0.7$

Membrane stress Sm acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})}{As}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2} + \frac{(D_p - d_a)}{2} \cdot t_e \cdot f_{r4}$$

$$l_m = Min \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = Min \left\{ \begin{array}{l} h_a \\ \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. App.1-7(b)(4)

$S_m \leq S$

Bending stress Sb acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{44.45 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$

E.4.5.4 - Openings in shells and heads according to ASME BPVC VIII UG-37, 2017 Edition

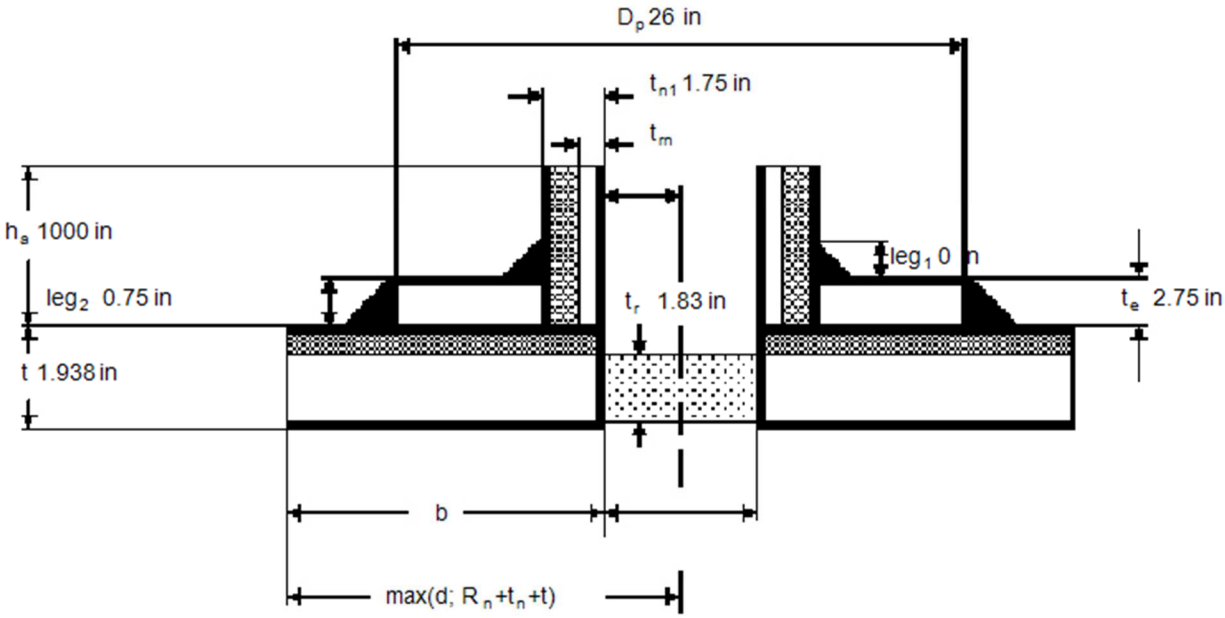
Set-on nozzle with reinforcement

Design pressure	p_D	425	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	***425***	psi
Calculation temperature	T_0	*800*	°F
Factor (1=internal pressure; 2=external pressure)	Γ	1	

Shell

Straight cross section (=Y), as cylinders acc. UG-36(b)(1) and flat heads acc. UG-39(b)(1) or circular cross section (=N) as spheres	Cyl	Y	(N=No)
Outside diameter	D_a	*100*	in
Nominal thickness without allowances	t	1.938	in
Required thickness (acc. UG27/32)	t_r	1.83	in
Available shell length for reinforcment	b_a	1000	in
Joint efficiency factor	E_1	1	
Material *K02700-SA-516-70-Class:-Size:*			
Material strength	K	11992	psi
Safety factor	S	1	
Allowable stress value K/S	S_v	***11992***	psi
Wall thickness allowance	c_{1s}	*0*	in
Corrosion allowance	c_{2s}	*0.0625*	in

Nozzle Nº 1



Access opening		No	
Outside diameter	d_a	19.5	in
Joint efficiency factor	E_n	1	
Material K02700-SA-516-70-Class:-Size:			
Material strength	K_n	11993	psi
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0.03937	in
Safety factor	S	1	
Allowable stress value K_n/S	S_n	**11993**	psi
Nominal thickness with allowances	t_{n1}	1.75	in
Actual wall thickness with allowances acc. Table UG-45	t_{b3}	**0.3677**	in
Nominal inside diameter = da-2*t2	d_{iN}	**16**	in
Inside diameter, corroded = d_a-2·t_n	d	**16.08**	in
External projection	h_a	1000	in
Angle between the shell axis and the sectional plane through the opening center	Θ	0	°
Nominal thickness without allowances	t_n	**1.711**	in
Required nozzle neck thickness per UG-27	t_a	**0.3305**	in
Required shell wall thickness where the nozzle neck attaches to the vessel (acc.UG27) with joint efficiency E=1.0	t_{b1}	**1.803**	in
Required nozzle neck thickness per UG-45	t_{UG-45}	**0.3677**	in

Reinforcing element

Thickness	t_e	2.75	in
Outside diameter	D_p	26	in
Material K02700-SA-516-70-Class:-Size:			
Material strength	K_p	11993	psi
Safety factor	S	1	
Allowable stress	S_p	**11993**	psi
Fillet nozzle/ reinforcement outside	leg_1	0	in
Fillet of reinforcement / shell outside	leg_2	0.75	in
Groove nozzle / shell (≤tn)	leg_4	0.812	in
Groove reinforcement / nozzle(≤te)	leg_5	0	in

Calculation according to		**UG-40**		**App.1-7**	
Correction factor (Fig.UG-37, int. pres.)	F	**1**			
Reserve of shell	$(E_1 \cdot t - F \cdot t_r)$	**0.108**	in		
Limit length of vessel acc. to UG-40(b)	b	**8.039**	in		in
Limit length of nozzle outside, UG40(c)	h'_a	**4.845**	in	**4.845**	in
Minimum required thickness of nozzle	t_{rn}	**0.2911**	in	**0.2911**	in
Projected Area	A	**18983**	mm²		in²
Area of shell reserve	A_1	**1.737**	in²		mm²
Area of reinforcement (A_2 to A_5)	A_V	**20770**	mm²		mm²
Total available area ∑A	∑A	**21890**	mm²		mm²
Required area A/Γ	A/H	**18983**	mm²		mm²
Utilization	A_{req}/A_{avl}	**86.72**	%		%
Allowable pressure (Approx.: pD/utilization)		**490.1**	psi		psi
Save values as adjacent nozzle (1..9)		(1..9)			

Weld loads according to UG-41

W = $[A-A_1+2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	=	**1476986**	N
W_1-1 = $[A_2+A_5+A_{41}+A_{42}] \cdot S_v$	=	**1717316**	N
W_2-2 = $[A_2+A_{41}] \cdot S_v$	=	**733773**	N

Strength of fillet welds

Reinf./nozzle	$\pi/2 \cdot d_a \cdot leg_1 \cdot 0.49 \cdot \min(S_p;S_n)$	**0**	N
Reinf./shell	$\pi/2 \cdot D_p \cdot leg_2 \cdot 0.49 \cdot \min(S_p;S_v)$	**800650**	N

Groove weld

Shell /Nozzle	$\pi/2 \cdot d_a \cdot leg_4 \cdot 0.60 \cdot \min(S_v;S_n)$	**726240**	N
Reinf./nozzle	$\pi/2 \cdot d_a \cdot leg_5 \cdot 0.74 \cdot \min(S_p;S_n)$	**0**	N

Comparison of loads on path 1-1 and 2-2

1-1			**800650**	N	+	**726240**	N	=	**1526890**	N
								≥	**1476986**	N
2-2	**0**	N	+	**0**	N	+	**726240**	N	=	**726240**	N
								≥	**733773**	N

Equations according to UG-40 and App.1-7

$$b = Max\left\{\begin{array}{l}\frac{d}{2}\\ t_n + t\end{array}\right. = Max\left\{\begin{array}{l}\frac{d}{2}\\ t_n + t\end{array}\right. = 204.2 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = Max\left\{\begin{array}{l}\frac{3 \cdot d/2}{4}\\ t_n + t\end{array}\right.$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot d \cdot t_r \cdot F$$

App.1-7(a)(1)

$$A = d \cdot t_r \cdot F = 408.4 \text{ mm} \cdot 46.48 \text{ mm} \cdot 1 = 18983 \text{ mm}^2$$

Fig. UG-37.1

Available shell thickness with allowances $t+c_{1s}+c_{2s}$	t_s	***2.001***	in
Required shell thickness with allowances t_r+...	t_{sr}	**1.893**	in
Required nozzle thickness with allowances	t_{rn+}	**0.3305**	in

Areas according to UG-40

$$h'_a = Min\begin{cases} 2.5 \cdot t \\ 2.5 \cdot t_n + t_e = 123.1 \text{ mm} \\ h_a \end{cases}$$

$$t_{rm} = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06 \cdot p_0)} = 29.3 \text{ bar} \cdot \frac{\frac{408.4 \text{ mm}}{20}}{(82.69 \text{ N/mm}^2 - 0.06 \cdot 29.3 \text{ bar})} = 7.394 \text{ mm} \quad \text{(internal pressure)}$$

$$A_1 = Max\begin{cases} d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \end{cases} =$$

$$Max\begin{cases} 408.4 \text{ mm} \cdot 2.743 \text{ mm} - 2 \cdot 43.45 \text{ mm} \cdot 2.743 \text{ mm} \cdot (1 - f_{r1}) \\ 2 \cdot (49.23 \text{ mm} + 43.45 \text{ mm}) \cdot 2.743 \text{ mm} - 2 \cdot 43.45 \text{ mm} \cdot 2.743 \text{ mm} \cdot (1 - f_{r1}) \end{cases} = 1120 \text{ mm}^2$$

$$A_2 = 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot h'_a = 2 \cdot (43.45 \text{ mm} - 7.394 \text{ mm}) \cdot 1 \cdot 123.1 \text{ mm} = 8874 \text{ mm}^2$$

$$A_{41} = (leg_1)^2 \cdot f_{r3} = (0 \text{ mm})^2 \cdot 1 = 0 \text{ mm}^2$$

$$A_{42} = (leg_2)^2 \cdot f_{r4} = (19.05 \text{ mm})^2 \cdot 1 = 362.9 \text{ mm}^2$$

$$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4} = (660.4 \text{ mm} - 408.4 \text{ mm} - 2 \cdot 43.45 \text{ mm}) \cdot 69.85 \text{ mm} \cdot 1 = 11532 \text{ mm}^2$$

$$A_V = A_2 + A_{41} + A_{42} + A_5 = A_2 + A_{41} + A_{42} + A_5 = 20770 \text{ mm}^2$$

App.1-7 is additionally required according to UG-36(b), if

D_a	*2540* ≤ 1520mm (60in.):	d_a	495.3	> Min [	*2540*/2; 508mm (20in.)]
D_a	*2540* > 1520mm (60in.):	d_a	495.3	> Min [	*2540*/3; 1000mm (40in.)]

Large cylinder opening acc. Appendix 1-7(b) not required

Total available area		A_{avl}	mm²
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{mn}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	mm^4
Material area acc. to Fig.1-7-1		A_s	mm²
Support length nozzle	Min[h_a; $t_e + (R_{nm} \cdot t_n)^{0.5}$]	l_{nm}	in
Support length shell	Min[b_a; $(R_m \cdot t_e)^{0.5}$]	l_m	in

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R = > 1524 mm (60 in.)$

(b) $2 \cdot R_n =$ > 1016 mm (40 in.) and $2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t}$

(c) $\frac{R_n}{R} =$ [redacted] = [redacted] ≤ 0.7

Membrane stress Sm acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})}{As}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2} + \frac{(D_p - d_a)}{2} \cdot t_e \cdot f_{r4}$$

$$l_m = Min\left\{ \frac{b_a}{\sqrt{R_m \cdot t}} \right.$$

$$l_{nm} = Min\left\{ \frac{h_a}{\sqrt{R_{nm} \cdot t_n}} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. App.1-7(b)(4)

$$S_m \le S$$

Bending stress Sb acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{49.23\ \text{mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \le 1.5 \cdot S$$

E.4.5.6 - Openings in shells and heads according to ASME BPVC VIII UG-37, 2017 Edition

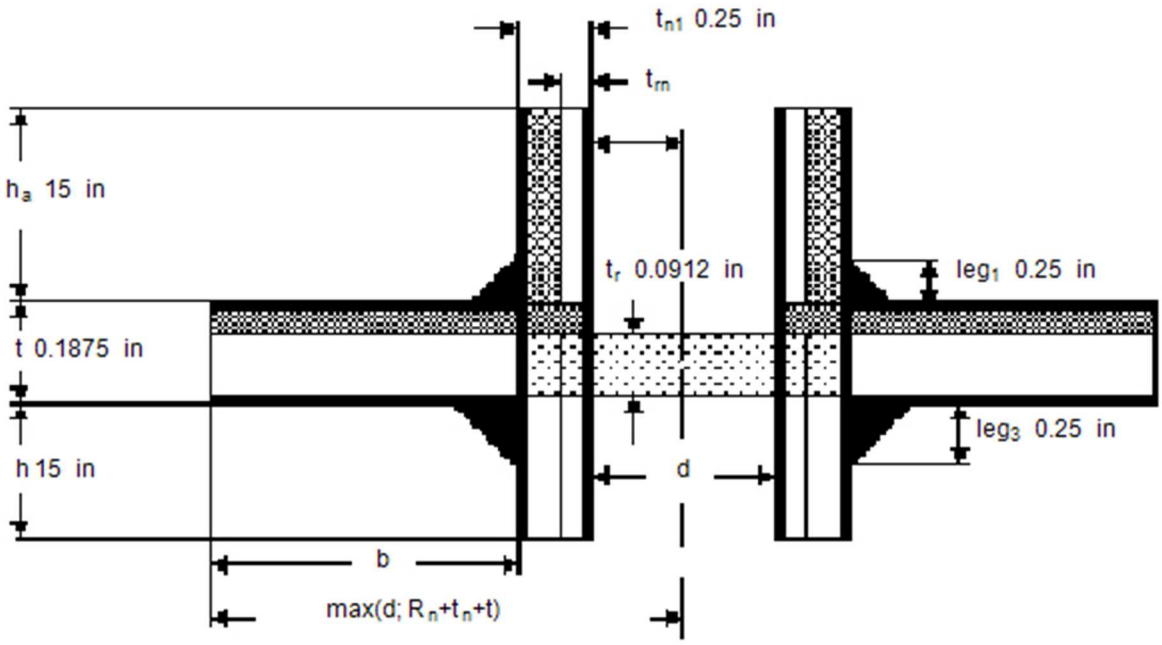
Protruding nozzle without reinforcement

Design pressure	p_D	150	psi
Hydrostatic head	D_p	0	psi
Calculation pressure	p_0	***150***	psi
Calculation temperature	T_0	*400*	°F
Factor (1=internal pressure; 2=external pressure)	Γ	1	

Shell

Straight cross section (=Y), as cylinders acc. UG-36(b)(1) and flat heads acc. UG-39(b)(1) or circular cross section (=N) as spheres	Cyl	N	(N=No)
Outside diameter	D_a	*24*	in
Nominal thickness without allowances	t	0.1875	in
Required thickness (acc. UG27/32)	t_r	0.0912	in
Available shell length for reinforcement	b_a	1000	in
Joint efficiency factor	E_1	1	
Material *S31651-SA-376-TP316N-Class:-Size:*			
Material strength	K	17604	psi
Safety factor	S	1	
Allowable stress value	S_v	***17604***	psi
Wall thickness allowance	c_{1s}	*0*	in
Corrosion allowance	c_{2s}	*0*	in

Nozzle Nº 1



Access opening		No	
Outside diameter	d_a	8.625	in
Joint efficiency factor	E_n	1	
Material S31600-SA-249-TP316-Class:-Size:			
Material strength	K_n	12116	psi
Wall thickness allowance	c_1	0	in
Allowance (corrosion)	c_2	0	in
Safety factor	S	1	
Allowable stress K_n/S	S_n	**12116**	psi
Nominal thickness with allowances	t_{n1}	0.25	in
Actual wall thickness with allowances acc. Table UG-45	t_{b3}	**0.2819**	in
Nominal inside diameter = da-2*t2	d_{iN}	**8.125**	in
Inside diameter, corroded = d_a-2·t_n	d	**8.125**	in
External projection	h_a	15	in
Internal projection	h	15	in
Angle between the shell axis and the sectional plane through the opening center	Θ	0	°
Nominal thickness without allowances	t_n	**0.25**	in
Required nozzle neck thickness per UG-27	t_a	**0.05067**	in
Required shell wall thickness where the nozzle neck attaches to the vessel (acc.UG27) with joint efficiency E=1.0	t_{b1}	**0.05037**	in
Required nozzle neck thickness per UG-45	t_{UG-45}	**0.05067**	in
Fillet weld nozzle / shell outside	leg_1	0.25	in
Fillet weld nozzle / shell inside	leg_3	0.25	in
Groove weld nozzle / shell (≤t)	leg_4	0	in

Calculation according to		**UG-40**		**App.1-7**	
Correction factor (Fig.UG-37, int. pres.)	F	**1**			
Reserve of shell	$(E_1 \cdot t - F \cdot t_r)$	**0.0963**	in		
Limit length of vessel acc. to UG-40(b)	b	**4.063**	in		in
Limit length of nozzle outside, UG40(c)	h'_a	**0.4688**	in	**0.4688**	in
Limit length of nozzle inside,Fig.UG37	h'	**0.4688**	in	0	
Minimum required thickness of nozzle	t_{rn}	**0.05067**	in	**0.05067**	in
Required area for internal pressure	A	**487.2**	mm²		in²
Area of shell reserve	A_1	**0.7674**	in²		mm²
Area of reinforcement (A_2 to A_5)	A_V	**242.5**	mm²		mm²
Total available area ∑A	A_{avl}	**737.7**	mm²		mm²
Required area A/Γ	A_{req}	**487.2**	mm²		mm²
Utilization	A_{req}/A_{avl}	**66.05**	%		%
Allowable pressure (approx.: p_D/utilization)		**227.1**	psi		psi
Save values as adjacent nozzle (1...9)		(1...9)			

Weld loads according to UG-41

W	= $[A-A_1+2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t-F \cdot t_r)] \cdot S_v$	=	**1639**	N
W_1-1	= $[A_2+A_{41}] \cdot S_v$	=	**13440**	N
W_2-2	= $[A_2+A_3+A_41+A_{43}+2 \cdot t \cdot t_n \cdot f_{r1}] \cdot S_v$	=	**34493**	N

Strength of nozzle wall, fillet and groove welds

Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot leg_1 \cdot 0.49 \cdot \min(S_v;S_n)$	=	**89447**	N
Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot leg_3 \cdot 0.49 \cdot \min(S_v;S_n)$	=	**89447**	N
Groove shell /nozzle	$\pi/2 \cdot d_a \cdot leg_4 \cdot 0.74 \cdot \min(S_v;S_n)$	=	**0**	N
Nozzle wall	$\pi/2 \cdot d_m \cdot t_n \cdot 0.70 \cdot S_n$	=	**124078**	N

Comparison of weld loads on path 1-1 and 2-2

1-1	**89447** N	+	**124078** N	=	**213525**	N		
				≥	**1639**	N		
2-2	**89447** N	+	**0** N	+	**89447** N	=	**178894**	N
				≥	**1639**	N		

Equations according to UG-40 and App.1-7

$$b = Max\left\{\begin{array}{l}\frac{d}{2}\\ t_n + t\end{array}\right. = Max\left\{\begin{array}{l}\frac{d}{2}\\ t_n + t\end{array}\right. = 103.2 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = Max\left\{\begin{array}{l}\frac{3 \cdot d/2}{4}\\ t_n + t\end{array}\right.$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$

App.1-7(a)(1)

$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) =$$

$$206.4 \text{ mm} \cdot 2.316 \text{ mm} \cdot 1 + 2 \cdot 6.35 \text{ mm} \cdot 2.316 \text{ mm} \cdot 1 \cdot (1 - 0.6882) = 487.2 \text{ mm}^2$$

Fig. UG-37.1

Available shell thickness with allowances $t+c_{1s}+c_{2s}$	t_s	***0.1875***	in
Required shell thickness with allowances t_r+...	t_{sr}	**0.0912**	in
Required nozzle thickness with allowances	t_{rn+}	**0.05067**	in

Areas according to UG-40

$$h'_a = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h_a \end{Bmatrix} = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h_a \end{Bmatrix} = 11.91\ \text{mm}$$

$$h' = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h \end{Bmatrix} = Min\begin{Bmatrix} 2.5\cdot t \\ 2.5\cdot t_n \\ h \end{Bmatrix} = 11.91\ \text{mm}$$

$$t_{rn} = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06\cdot p_0)} =$$

(internal pressure)

$$10.34\ \text{bar} \cdot \frac{\frac{206.4\ \text{mm}}{20}}{(83.54\ \text{N/mm}^2 - 0.06\cdot 10.34\ \text{bar})} = 1.287\ \text{mm}$$

$$A_1 = Max\begin{Bmatrix} d\cdot(E_1\cdot t - F\cdot t_r) - 2\cdot t_n\cdot(E_1\cdot t - F\cdot t_r)\cdot(1-f_{r1}) \\ 2\cdot(t+t_n)\cdot(E_1\cdot t - F\cdot t_r) - 2\cdot t_n\cdot(E_1\cdot t - F\cdot t_r)\cdot(1-f_{r1}) \end{Bmatrix} =$$

$$Max\begin{Bmatrix} 206.4\ \text{mm}\cdot 2.446\ \text{mm} - 2\cdot 6.35\ \text{mm}\cdot 2.446\ \text{mm}\cdot(1-0.6882) \\ 2\cdot(4.762\ \text{mm}+6.35\ \text{mm})\cdot 2.446\ \text{mm} - 2\cdot 6.35\ \text{mm}\cdot 2.446\ \text{mm}\cdot(1-0.6882) \end{Bmatrix} = 495.1\ \text{mm}^2$$

$$A_2 = 2\cdot(t_n - t_{rn})\cdot f_{r2}\cdot h'_a = 2\cdot(6.35\ \text{mm} - 1.287\ \text{mm})\cdot 0.6882\cdot 11.91\ \text{mm} = 82.98\ \text{mm}^2$$

$$A_3 = 2\cdot(t_n - c_2)\cdot f_{r2}\cdot h' = 2\cdot(6.35\ \text{mm} - 0\ \text{mm})\cdot 0.6882\cdot 11.91\ \text{mm} = 104.1\ \text{mm}^2$$

$$A_{41} = (leg_1)^2\cdot f_{r2} = (6.35\ \text{mm})^2\cdot 0.6882 = 27.75\ \text{mm}^2$$

$$A_{43} = (leg_3)^2\cdot f_{r2} = (6.35\ \text{mm})^2\cdot 0.6882 = 27.75\ \text{mm}^2$$

$$A_V = A_2 + A_3 + A_{41} + A_{43} = A_2 + A_3 + A_{41} + A_{43} = 242.5\ \text{mm}^2$$

App.1-7 is additionally required acc. to UG-36(b) if

D_a	*609.6* ≤ 1520mm (60in.):	d_a	219.1	> Min [	*609.6*/2; 508mm (20in.)]
D_a	*609.6* > 1520mm (60in.):	d_a	219.1	> Min [	*609.6*/3; 1000mm (40in.)]

Additional rules for cylindr. shells, App.1-7(b) not required

Total available area		A_{avl}	mm²
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{mn}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	mm^4
Material area acc. to Fig.1-7-1		A_s	mm²
Support length nozzle	$Min[h_a; t_e + (R_{nm}\cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$Min[b_a; (R_m\cdot t_e)^{0.5}]$	l_m	in

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R =$ [redacted] $> 1524 mm (60 in.)$

(b) $2 \cdot R_n =$ [redacted] > 1016 mm (40 in.) and $2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t} =$ [redacted]

(c) $\frac{R_n}{R} =$ [redacted] $=$ [redacted] ≤ 0.7

Membrane stress Sm acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{[R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})]}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2}$$

$$l_m = Min \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = Min \left\{ \begin{array}{l} h_a \\ t_e + \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. to App.1-7(b)(4)

$S_m = \leq S$

Bending stress Sb acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{4.762 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$

Appendix: Material documentation

Section 2: Schale/UG27
Section 3: Mantel/UG37
Section 3: Stutzen/UG37
Section 3: Verstaerkung/UG37
Section 4: Mantel/UG37
Section 4: Stutzen/UG37
Section 5: Mantel/UG37
Section 5: Stutzen/UG37
Section 6: 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]: 24,55
Thickness [mm]: 42,86 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	Tensile str. 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 (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··· W/Km	Heat··· cond. J/kgK	Heat··· capac. J/kgK
7,85···	12,1···	12,7···	13,3···	13,8···	14,4···	·····	·····	·····	·····	·····	·····

Section 8: Mantel/UG37

Material specification:

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

Design conditions and dimensions:

Temperature [°C]: 426,67 Pressure [bar]: 29,3
Thickness [mm]: 49,23 Outside diameter [mm]: 2540

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	82,68
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	82,68
Modulus of elasticity [kN/mm²]:	202	166,1994

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·····

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					

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Section 8: Stutzen/UG37
Section 8: Verstaerkung/UG37

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]: 426,6667 Pressure [bar]: 29,3029
Thickness [mm]: 2 Outside diameter [mm]: 0

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	82,69
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	82,69
Modulus of elasticity [kN/mm²]:	202	166,2

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

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					

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Section 9: Mantel/UG37

Material specification:

Regulation:	ASMET1A:2017Spec. No.:	SA-376	Product: Smls. pipe
Material code:	S31651-SA-376-TP316N-Class:-Size:		Short name: 16Cr-12Ni-2Mo-N

Design conditions and dimensions:

Temperature [°C]:	204,44	Pressure [bar]:	10,34
Thickness [mm]:	4,76	Outside diameter [mm]:	609,6

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	158,00	121,38
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	158,00	121,38
Modulus of elasticity [kN/mm²]:	195	182,6448

Notes:
G12 General Requirements
At temperatures above 550°C, these stress values apply only when the carbon is 0.04% or higher on heat analysis.

H1 Heat Treatment Requirements
For temperatures above 550°C, these stress values may be used only if the material is heat treated by heating to the minimum temperature specified in the material specification, but not lower than 1040°C, and quenching in water or rapidly cooling by other means.

T8 Time-Dependent Properties
Allowable stresses for temperatures of 595°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
		141	131	122	115	109	104	99.9

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
	96.1	93.1	90.1	81.6	50.4		

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
146	201	209	204	195	189	186	183	179	176	172	169	165	160	156

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

600	700
151	140

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	16,2	17,0	17,7	18,1	18,6					

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Section 9: Stutzen/UG37

Material specification:

Regulation:	ASMET1A:2017	Spec. No.:	SA-249	Product:	Wld. tube
Material code:	S31600-SA-249-TP316-Class:	-Size:		Short name:	16Cr-12Ni-2Mo

Design conditions and dimensions:

Temperature [°C]:	204,4444	Pressure [bar]:	10,3422
Thickness [mm]:	2	Outside diameter [mm]:	0

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	117,00	83,54
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	117,00	83,54
Modulus of elasticity [kN/mm²]:	195	182,6445

Notes:
G3 General Requirements
These stress values include a joint efficiency factor of 0.85.

G12 General Requirements
At temperatures above 550°C, these stress values apply only when the carbon is 0.04% or higher on heat analysis.

G24 General Requirements
A factor of 0.85 has been applied in arriving at the maximum allowable stress values in tension for this material. Divide tabulated values by 0.85 for maximum allowable longitudinal tensile stress.

T9 Time-Dependent Properties
Allowable stresses for temperatures of 620°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
	99.8	90.8	84.0	78.8	74.7	72.1	69.6	

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
	68.4	67.1	65.9	64.0	42.9	25.3	8.90

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
146	201	209	204	195	189	186	183	179	176	172	169	165	160	156

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

600	700
151	140

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	16,2	17,0	17,7	18,1	18,6					