



**EN 14025: Tanks für die Beförderung gefährlicher Güter**  
**EN 14025: Tanks for the transport of dangerous goods**

**Module ADR**

## Contents in English and German

Literature / Literatur: [www.beuth.com](http://www.beuth.com)

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## **Modul ADR: Mindestdicke und Prüfdruck nach EN 14025/ADR/RID**

### ***Programmbeschreibung***

Mit Modul ADR können erforderlichen Mindestdicken und der Berechnungsdruck nach EN 14025 und ADR berechnet werden. In Anhang A von EN 14025 werden Auszüge von ADR (Europäisches Übereinkommen über die internationale Beförderung gefährlicher Güter auf der Straße / Accord européen relatif au transport international des marchandises Dangereuses par Route) und RID (Regelung zur internationalen Beförderung gefährlicher Güter im Schienenverkehr) zitiert.

EN 14025 verlangt die Berücksichtigung eines dynamischen Drucks  $P_{dyn}$  bei doppelter Erdbeschleunigung  $2 \cdot g$  in Längsrichtung. Der Berechnungsdruck  $P_C$  nach ADR hängt auch vom Dampfdruck bei  $50^\circ\text{C}$   $p_{vap}$  und dem Siedepunkt (über oder unter  $35^\circ\text{C}$ ) ab. Eine Tabelle für den Prüfdruck ist in En 14025 Anhang A.4 enthalten.

Die Mindestdicke nach ADR/RID wird mit den Gleichungen (A.3), (A.4) und (A.5) berechnet. Verschiedene Bedingungen für den Werkstoff nach Appendix A werden geprüft.

Die Eingabedaten und erforderlichen Gleichungen sind in der Berechnungsmaske aufgeführt. Ein Beispiel dazu wird in Abschnitt 1 ADR B.3+4 weiter unten dokumentiert.



## **Module ADR: Minimum thickness and test pressure acc. to EN 14025/ADR/RID**

### ***Program description***

With module ADR the required minimum thicknesses and the calculation pressure according to EN 14025 and ADR can be calculated. Appendix A of EN 14025 quotes extracts from ADR (*European Convention on the Transport of Dangerous Goods*) and RID (*Convention concerning International Carriage by Rail*).

EN 14025 requires consideration of a dynamic pressure  $P_{dyn}$  under twice the gravitational acceleration  $2 \cdot g$  in axial direction. The calculation pressure  $PC$  acc. to ADR depends also on the vapor pressure at  $50^\circ\text{C}$   $p_{vap}$  and the boiling point (over or under  $35^\circ\text{C}$ ). A table for the test pressure is given in EN 14025 Appendix A.4.

The minimum thickness acc. To ADR/RID is calculated with equations (A.3), (A.4) and (A.5). Some conditions for the material according to Appendix A are checked.

The input data and required equations are listed in the calculation mask of the program. An example for module ADR is documented in section 1 ADR B.3+4 below.



### Example EN 14025 Appendix B

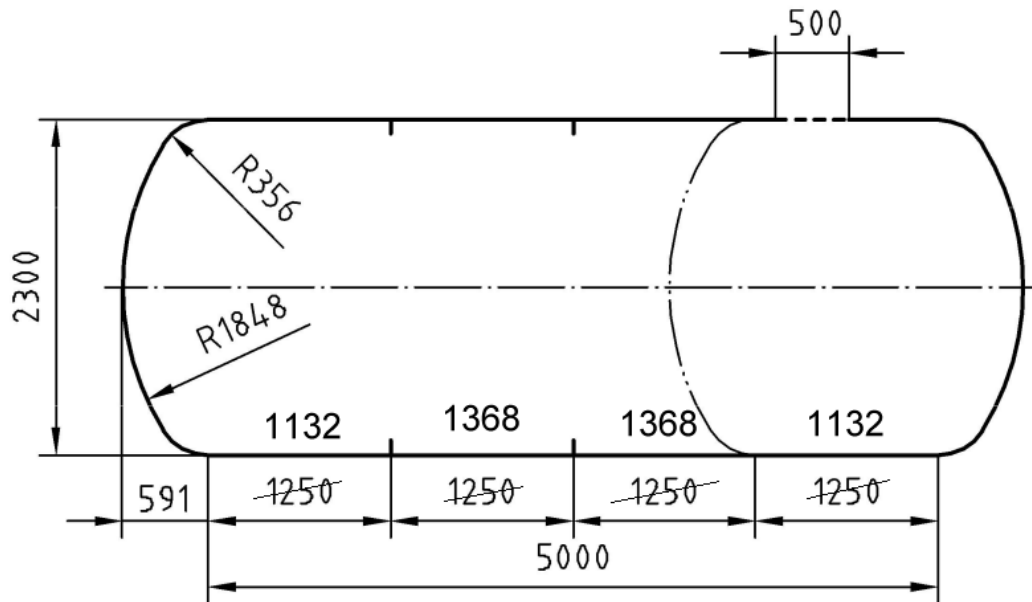


Fig.: Calculation example with dimensions in mm acc. En 14025

#### Appearance

Input values:	1.234	or	1.234
Calculated values:	<b>1.234</b>	or	<b>1.234</b>
Critical values:	<b>1.234</b>	or	<b>1.234</b>
Estimated values:	<b>1.234</b>	or	<b>1.234</b>



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Module ADR

**01 ADR B34**

**Minimum wall thickness acc. to EN 14025/ADR DIN EN 14025:2008-08**

**Minimum thickness and test pressure acc. to EN 14025/ADR**

Calculation temperature	T	100	°C
Filling/draining pressure (0 for gravity draining)	PF	0.3	MPa
Maximum filling height (>0 for gravity draining)	HF	2300	mm
Outside diameter	Da	2300	mm
Weld joint factor	lamS	0.8	-
Minimum thickness acc. to ADR 6.8.2.1.18 (for structural steel: 5mm for D≤ 1800mm, 6 mm for D>1800mm)	e0	<b>6</b>	mm
Specific weight of fill medium	gamF	1	kg/dm <sup>3</sup>
Vapor pressure at 50°C	Pvap	0.2	MPa
Boiling point over 35°C (0=No 1=Yes)	SP	0	(0,1)
Total weight with charge	GW	34000	kg
Dead weight	Tare	4000	kg
Type of material (1=fine grain steel, 2=other steel, 3=aluminum)	WS	2	(1-3)
Material code	Nr.	1.4404(H	
Strength (Operation, exception, Rp, Rm etc.)	K	430	MPa
Safety factor (Operation, exception)	S	3	-
Tensile strength at 20°C	Rm20	<b>530</b>	MPa
Proof stress at 20°C Rp02, Rp1	Rp20	<b>260</b>	
Allowable stress at operation acc. to EN 14025	f	<b>143.3</b>	MPa
All. Stress for ADR/RID Min[0.5*Rm20; 0.75*Rp20]	fT	<b>195</b>	MPa
Rupture elongation	A1	40	%

**— Results —**

Operation pressure acc. to EN14025 6.2 Max(PB, MWP)	PEN	<b>0.3</b>	MPa
Required wall thickness Min(eT, eC, e1)	eMin	<b>3.635</b>	mm
Material: <b>Conditions satisfied!</b>			
Calculation pressure	PC	<b>4</b> bar	= PC <b>0.4</b> MPa
Test pressure	Ptest	<b>4</b> bar	= PT <b>0.4</b> MPa
Static pressure component	Pstat	<b>0.023</b>	MPa
Max(PF, Pstat)	MWP	<b>0.3</b>	MPa
Dynamic pressure	Pdyn	<b>0.1417</b>	MPa
Dynamic operation pressure Pvap - 0.1MPa + Pdyn	PB	<b>0.2417</b>	MPa
Minimum thickness for testing acc. (A.3)	eT	<b>2.949</b>	mm
Minimum thickness for operation acc. (A.4)	eC	<b>2.359</b>	mm
Equivalent thickness	e1	<b>3.635</b>	mm



— Equations for P —

$$P_{dyn} = \text{Max}(0.035; (GW-Tara) * 2 * 9.81 / (\text{Pi}/4 * A^2)) \quad 6.2 \text{ Table 1}$$

$$0.1417 = \text{Max}(0.035; (34000 - 4000) * 2 * 9.81 / (\text{Pi}/4 * 2300^2))$$

$$p_B = P_v - 0.1 + P_{dyn} = 0.2 - 0.1 + 0.1417 = 0.2417$$

PC = 0.4 = Calculation pressure acc. ADR 6.8.2.1.18 distinguishes among:

For  $P_{vap} = 0.2 \leq 0.11$  holds:

$$PC = 2 * P_{stat} = 2 * 0.023 \text{ for } (PF = 0.3 = 0)$$

$$PC = 1.3 * PF = 1.3 * 0.3 \text{ for } (PF = 0.3 <> 0)$$

For  $P_{vap} = 0.2 > 0.11$  holds:

$$PC_{min} = 0.15 \text{ for } (SP = 0 = 1, \text{ Boiling point } > 35^\circ\text{C})$$

$$PC_{min} = 0.4 \text{ for } (SP = 0 = 0, \text{ Boiling point } \leq 35^\circ\text{C})$$

$$PC = \text{Max}(PC_{min}, 1.3 * PF) = \text{Max}(PC_{min}, 1.3 * 0.3)$$

Test pressure  $P_T$  acc. to Table Appendix A.4 and 6.8.2.4.1 ADR/RID in bar

Calculation pressure PC [bar] G 1.5 2.65 4 10 15 21

Test pressure [bar] G 1.5 2.65 4 4 4 10

with  $G = P_{stat}$  for gravity draining ( $PF=0$ )

— Equations for e —

$$e_T = P_T * A / (2 * f_{Fpr} * \lambda_m) \quad (A.3)$$

$$2.949 = 0.4 * 2300 / (2 * 195 * 0.8)$$

$$e_C = PC * A / (2 * f_{Fpr}) \quad (A.4)$$

$$2.359 = 0.4 * 2300 / (2 * 195)$$

$$e_l = 464 * e_0 / (R_m F * A_1)^{(2/3)} \quad \text{Gl. (A.5) and ADR 6.8.2.1.18}$$

$$3.635 = 464 * 6 / (530 * 40)^{(2/3)}$$

— Conditions for the material —

A.2.12 Section 6.8.2.1.11: For welded steel tanks holds

$$R_e / R_m = 260 / 530 = 0.4906 \leq 0.85$$

A.2.13 Section 6.8.2.1.12: For the rupture elongation holds

$$A = 40 \geq 18.87 = 10000 / R_m$$

For fine grain steels:  $A \geq 16\%$

For other steels:  $A \geq 20\%$

For aluminum alloys:  $A \geq 12\%$

**Conditions satisfied!**



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Module ADR

**02 EN07 B.5.1**

**Shells under internal pressure DIN EN 13445-3/7:2003-11 (State Nov.2005) and EN14025:2008-08**

**7.4.2 Cylindrical shells under internal pressure**

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Regulation (0=EN13445-3, 1=EN14025)	TFZ	1 (0,1)
EN 14025: Tanks for the transport of dangerous goods		
Load case: Operation = 1 / Test = 2	lc	2 1,2
Calculation temperature	t	100 °C
Calculation pressure	P	4 bar
Final wall thickness acc. drawing	en	5 mm
Outside diameter	De	<b>2310</b> mm
Weld factor ( $=\lambda$ acc. EN 14025)	Z	0.8

**Material:**

Material designation	Number 1.4404 (H)
Wall thinning allowance	$\delta_e$ 0 mm
Corrosion allowance	c 0 mm
Thinning allowance during manufacturing	$\delta_m$ 0 mm
Sum of allowances	$\Sigma(\delta)$ <b>0</b> mm
Material strength (Re, Rp, Rm)	K <b>260</b> MPa
Safety factor acc. EN 13445	S <b>1.05</b>
Allowable stress	f <b>195</b> MPa

**Result**

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Inside diameter	Di	2300 mm
Mean diameter	Dm	<b>2305</b> mm
Geometrical ratio	e/De	<b>0.001278</b>
Analysis thickness $en - \Sigma(\delta)$	ea	<b>5</b> mm
Required thickness	e	<b>2.953</b> mm
Required thickness with allowances	e $\delta$	<b>2.953</b> mm
Maximum permissible pressure	Pmax	<b>0.6768</b> MPa

Load case **Test**  
The strength condition is **valid**  
The geometrical condition is **valid**



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— **Allowable stress for testing acc. EN 14025** —

Tensile strength at 20°C	Rm20	<b>530</b> MPa
Yield stress Re at 20°C (Rp02 or Rp1)	Re	<b>260</b> MPa
Allowable stress = Min[0.5*Rm20, 0.75*Re]	f	<b>195</b> MPa
f = Min[0.5* <b>530</b> MPa , 0.75* <b>260</b> MPa ] = <b>195</b> MPa		

— **Equations** —

$$e = P * D_i / ( 2 * f * Z - P ) = \mathbf{2.953} \text{ mm} \quad (7.4-1), \text{ EN 14025 (1)}$$

$$e = \frac{0.4 * 2300}{2 * \mathbf{195} * 0.8 - 0.4}$$

The strength condition is **valid** :

$$e_a = \mathbf{5} \geq \mathbf{2.953} = e$$

The geometrical condition is **valid** :

$$e/D_e = \mathbf{0.001278} = \mathbf{2.953} / \mathbf{2310} \leq 0.16$$

$$P_{\max} = P * f * Z * e_a / D_m = \mathbf{0.6768} \text{ MPa} \quad (7.4-3)$$

$$P_{\max} = \frac{0.4 * \mathbf{195} * 0.8 * \mathbf{5}}{\mathbf{2305}}$$



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Module ADR

**03 EN07 B.5.2**

**Shells under internal pressure DIN EN 13445-3/7:2003-11 (State Nov.2005) and EN14025:2008-08**

**7.5.3 Torispherical ends under internal pressure - Korbbogenboden type**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	1 (0,1)
EN 14025: Tanks for the transport of dangerous goods		
Load case: Operation = 1 / Test = 2		2 1,2
Calculation temperature	t	100 °C
Calculation pressure (ext. pres. acc.8.8.2: P<0)	P	4 bar
Final wall thickness according to drawing	en	5 mm
Outside diameter	De	2310 mm
Weld factor (=λ acc. EN 14025)	Z	1

**Material:**

Material designation	Number	1.4404 (H)
Wall thinning allowance	δe	0 mm
Corrosion allowance	c	0 mm
Thinning allowance during manufacturing	δm	0 mm
Sum of allowances	Σ(δ)	0 mm
Material strength (Re, Rp, Rm)	K	<b>260</b> MPa
0.2% proof stress, operation	Rp02T	<b>166</b> MPa
0.2% proof stress, room temperature	Rp02R	<b>220</b> MPa
Safety factor	S	<b>1.05</b>
Allowable stress (f=fd acc EN14025)	f	<b>195</b> MPa
Allowable buckling stress fb=fd=f acc. EN14025	fb	<b>195</b> MPa

**Results:**

Maximum permissible pressure Min(Ps, Py, Pb)	Pmax	<b>0.6542</b> MPa
Calculation thickness without allowance	ea	<b>5</b> mm
Required wall thickness Max(es, ey, eb)	e	<b>3.602</b> mm
Required thickness with allowances	eδ	<b>3.602</b> mm
Required thickness of spherical part, membrane	es	<b>1.896</b> mm
Required thickness of knuckle, yield 7.5.3.5	ey	<b>2.988</b> mm
Required thickness of knuckle, plastic buckling	eb	<b>3.602</b> mm
Inside diameter	Di	<b>2300</b> mm
Inside radius of spherical part	R	<b>1848</b> mm
Inside radius of knuckle	r	<b>355.7</b> mm
Geometrical ratio	R/De	<b>0.8</b>
Geometrical ratio	r/De	<b>0.154</b>
Calculation coefficient	β	<b>0.7891</b>
Thickness reduction distance √(R*e) acc. 7.5.3.4	l	<b>81.59</b> mm
Limit skirt length 0.2*√(Di*e) acc. 7.5.3.4	h	<b>18.2</b> mm

Loading case: **Test**  
 The strength condition is **valid**  
 The geometrical conditions are **valid**

**Allowable stress for testing acc. EN 14025**

Tensile strength at 20°C	Rm20	<b>530</b> MPa
Yield stress Re at 20°C (Rp02 or Rp1)	Re	<b>260</b> MPa
Allowable stress = Min[0.5*Rm20, 0.75*Rpe]	f	<b>195</b> MPa
f = Min[0.5* <b>530</b> MPa , 0.75* <b>260</b> MPa ] = <b>195</b> MPa		



**Equations**

$$e_s = P * R / ( 2 * f * Z - 0.5 * P ) = 1.896 \text{ mm}$$

$$e_s = 0.4 * 1848 / ( 2 * 195 * 1 - 0.5 * 0.4 )$$

$$e_y = \beta * P * (0.75 * R + 0.2 * D_i) / f = 2.988 \text{ mm}$$

$$e_y = 0.7891 * 0.4 * (0.75 * 1848 + 0.2 * 2300) / 195$$

The auxiliary values for  $\beta$  (X, Y, Z, N at the end of mask) have been calculated iteratively with the required thickness e.

$$e_b = (0.75 * R + 0.2 * D_i) * \left| \frac{P * (D_i/r)^{0.825}}{111 * f_b} \right|^{2/3} = 3.602$$

$$e_b = (0.75 * 1848 + 0.2 * 2300) * \left| \frac{0.4 * (2300 / 355.7)^{0.825}}{111 * 195} \right|^{2/3}$$

$$e = \text{Max}(e_b, e_y, e_s) = \text{Max}(3.602, 2.988, 1.896) = 3.602$$

The strength condition is **valid** :

$$e_a = 5 \geq 3.602 = e$$

The strength condition is **valid** :

$$\text{Max}(0.06 * D_i, 2 * e_a) \leq r \leq D_i / 5$$

$$\text{Max}(138, 10) \leq 355.7 \leq 460$$

$$D_e / 1000 \leq e_a \leq 0.08 * D_e, \quad 2.31 \leq 5 \leq 184.8$$

$$R = 355.7 \leq 2310 = D_e$$



**— Rating of the permissible pressure**

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$$P_s = 2 * f * Z * e_a / ( R + 0.5 * e_a ) = \mathbf{1.054}$$

$$P_s = 2 * \mathbf{195} * \mathbf{1} * \mathbf{5} / ( \mathbf{1848} + 0.5 * \mathbf{5} )$$

$$P_y = f * e_a / [ \beta * ( 0.75 * R + 0.2 * D_i ) ] = \mathbf{0.6693}$$

$$P_y = \mathbf{195} * \mathbf{5} / [ \mathbf{0.7891} * ( 0.75 * \mathbf{1848} + 0.2 * \mathbf{2300} ) ]$$

$$P_b = 111 * f_b * [e_a / (0.75 * R + D_i / 5)]^{1.5} * (r / D_i)^{0.825} = \mathbf{0.6542}$$

$$P_b = 111 * \mathbf{195} * [ \mathbf{5} / (3 * \mathbf{1848} / 4 + \mathbf{2300} / 5) ]^{1.5} * ( \mathbf{355.7} / D_i )^{0.825}$$

$$P_{max} = \min(P_b, P_y, P_s) = \max( \mathbf{0.6542}, \mathbf{0.6693}, \mathbf{1.054} ) = \mathbf{0.6542}$$

$$\text{Parameter: } Y = \mathbf{0.001949}, \quad Z = \mathbf{2.71}, \quad X = \mathbf{0.1547}, \quad N = \mathbf{0.8447}$$

$$\text{Parameter: } \beta_{0.06} = \mathbf{1.668}, \quad \beta_{0.1} = \mathbf{1.104}, \quad \beta_{0.2} = \mathbf{0.5281}$$

$$\beta = \mathbf{0.7891}$$

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**04 EN08 B.5.3**

**Shells under external pressure DIN EN 13445-3/7 edition 2003-11 (state Nov.2005)**

**Spherical shells acc. to 8.7.1**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	1 (0,1)
EN 14025: Tanks for the transport of dangerous goods, section 6.4		
Load case: Operation = 1 / Test = 2	lc	2
Safety factor acc. to section 8.4.4	S	<b>1.1</b>
Calculation temperature	t	20 °C
Calculation pressure	P	4 bar
Final wall thickness with allowances	en	8 mm
Mean radius of the shell	R	1848 mm

**Material properties of the spherical shell:**

Material designation	Number	1.4404 (H)
Poisson's ratio	nu	0.3
Austenitic steel (1=yes, 2=no)		1
Wall thinning allowance	$\delta_e$	0 mm
Corrosion allowance	c	0 mm
Thinning allowance during manufacturing	$\delta_m$	0 mm
Sum of allowances	$\Sigma(\delta)$	<b>0</b> mm
Strength acc. to specification (Re, Rp, Rm)	K	<b>260</b>
Safety factor according to section 8.4.4	S	<b>1.1</b>
Modulus of elasticity	E	200000 MPa
0.2% proof stress at operation temperature	Rp02	220 N/mm <sup>2</sup>
0.2% proof stress at room temperature	Rp02p	220 MPa
allowable elastic limit (Rpx, Rpx/1.25)	$\sigma_e$	<b>176</b> N/mm <sup>2</sup>
Curvature deviation greater than 30%? 1=yes, 2=no, Abw		2
based on a max. arc length of measuring range	Bog	
maximum radius of curvature	RKmax	mm

**Results:**

Calculation thickness without allowances	ea	<b>8</b> mm
Limit pressure for circumferential yield (8.7.1-1)	py	<b>1.524</b> MPa
Theoretical instability pressure (8.7.1-2)	pm	<b>4.535</b> MPa
Ratio pm/py	pm/py	<b>2.976</b>
Ratio pr/py (Fig. 8.5-5)	pr/py	<b>0.4327</b>
allowable pressure (pr/S)	pzul	<b>0.5994</b> MPa

**Condition:** P = 0.4 < **0.5994** = pzul

The strength condition is **valid**  
for load case **Test**



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$$p_y = 1.524 = 2 * \sigma_e * e_a / R = 2 * 176 * 8 / 1848 -$$

$$p_m = 4.535 = 1.21 * E * e_a^2 / R^2 = 1.21 * 200000 * 8^2 / 1848^2$$

$$p_{zul} = \begin{cases} p_r/S = 0.6593 / 1.1, & \text{shape deviation} < 30\% \\ p_r/S * (1.3 * R / R_{Kmax})^2 = 0.6593 / 1.1 * (1.3 * 1848 / )^2 \end{cases}$$

Max. measuring length of curvature deviation acc. to 8.7.2:

$$B_{og} = = 2.4 * \sqrt{(e_a * R_{Kmax})} = 2.4 * \sqrt{( 8 * )}$$

**Vessel ends acc. to section 8.8:**

Semi-spherical ends shall be designed acc. to the rules for spheres.  
 The mean sphere radius for torispherical shells is R=crown outside radius  
 and for the stress calculation acc. 7.5.2 (inside pressure P<0 with  
 module EN07) holds N=1.  
 For semi-ellipsoidal ends the mean sphere radius is R=D<sup>2</sup>/(4h).



**05 EN07 B.6.1**

**Shells under internal pressure DIN EN 13445-3/7:2003-11 (State Nov.2005) and EN14025:2008-08**

**7.4.2 Cylindrical shells under internal pressure**

Regulation (0=EN13445-3, 1=EN14025) EN 14025: Tanks for the transport of dangerous goods	TFZ	1 (0,1)
Load case: Operation = 1 / Test = 2	lc	1 1,2
Calculation temperature	t	100 °C
Calculation pressure	P	3 bar
Final wall thickness acc. drawing	en	3.02 mm
Outside diameter	De	<b>2306</b> mm
Weld factor (=λ acc. EN 14025)	Z	0.8

**Material:**

Material designation	Number 1.4404 (H)
Wall thinning allowance	δe 0 mm
Corrosion allowance	c 0 mm
Thinning allowance during manufacturing	δm 0 mm
Sum of allowances	Σ(δ) 0 mm
Material strength (Re, Rp, Rm)	K <b>430</b> MPa
Safety factor acc. EN 13445	S <b>3</b>
Allowable stress	f <b>143.3</b> MPa

**Result**

Inside diameter	Di	2300 mm
Mean diameter	Dm	<b>2303</b> mm
Geometrical ratio	e/De	<b>0.001306</b>
Analysis thickness en - Σ(δ)	ea	<b>3.02</b> mm
Required thickness	e	<b>3.013</b> mm
Required thickness with allowances	eδ	<b>3.013</b> mm
Maximum permissible pressure	Pmax	<b>0.3007</b> MPa

Load case **Operation**  
 The strength condition is **valid**  
 The geometrical condition is **valid**

**Equations**

Allowable stress for the selected load case:

$$f = K/S = \frac{430 \text{ MPa}}{3} = 143.3 \text{ MPa}$$

$$e = P * Di / ( 2 * f * Z - P ) = \frac{3 * 2300}{2 * 143.3 * 0.8 - 3} = 3.013 \text{ mm} \quad (7.4-1), \text{ EN 14025 (1)}$$

The strength condition is **valid** :  
 $ea = 3.02 \geq 3.013 = e$

The geometrical condition is **valid** :  
 $e/De = 3.013 / 2306 \leq 0.16$

$$P_{max} = P * f * Z * ea / Dm = \frac{3 * 143.3 * 0.8 * 3.02}{2303} = 0.3007 \text{ MPa} \quad (7.4-3)$$



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**06 EN07 B.6.2**

**Shells under internal pressure DIN EN 13445-3/7:2003-11 (State Nov.2005) and EN14025:2008-08**

**7.5.3 Torispherical ends under internal pressure - Korbbojenboden type**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	1 (0,1)
EN 14025: Tanks for the transport of dangerous goods		
Load case: Operation = 1 / Test = 2		1 1,2
Calculation temperature	t	100 °C
Calculation pressure (ext. pres. acc.8.8.2: P<0)	P	3 bar
Final wall thickness according to drawing	en	3.654 mm
Outside diameter	De	2310 mm
Weld factor (=λ acc. EN 14025)	Z	1

**Material:**

Material designation	Number	1.4404 (H)
Wall thinning allowance	δe	0 mm
Corrosion allowance	c	0 mm
Thinning allowance during manufacturing	δm	0 mm
Sum of allowances	Σ(δ)	0 mm
Material strength (Re, Rp, Rm)	K	430 MPa
0.2% proof stress, operation	Rp02T	166 MPa
0.2% proof stress, room temperature	Rp02R	220 MPa
Safety factor	S	3
Allowable stress (f=fd acc EN14025)	f	143.3 MPa
Allowable buckling stress fb=fd=f acc. EN14025	fb	143.3 MPa

**Results:**

Maximum permissible pressure Min(Ps, Py, Pb)	Pmax	0.3 MPa
Calculation thickness without allowance	ea	3.654 mm
Required wall thickness Max(es, ey, eb)	e	3.654 mm
Required thickness with allowances	eδ	3.654 mm
Required thickness of spherical part, membrane	es	1.935 mm
Required thickness of knuckle, yield 7.5.3.5	ey	3.051 mm
Required thickness of knuckle, plastic buckling	eb	3.654 mm
Inside diameter	Di	2303 mm
Inside radius of spherical part	R	1848 mm
Inside radius of knuckle	r	355.7 mm
Geometrical ratio	R/De	0.8
Geometrical ratio	r/De	0.154
Calculation coefficient	β	0.7894
Thickness reduction distance √(R*e) acc. 7.5.3.4	l	82.17 mm
Limit skirt length 0.2*√(Di*e) acc. 7.5.3.4	h	18.35 mm

Loading case: **Operation**  
 The strength condition is **valid**  
 The geometrical conditions are **valid**



**Equations**

Allowable stress for the selected load case:

$$f = K/S = 430 \text{ MPa} / 3 = 143.3 \text{ MPa}$$

$$e_s = P * R / ( 2 * f * Z - 0.5 * P ) = 1.935 \text{ mm}$$

$$e_s = 0.3 * 1848 / ( 2 * 143.3 * 1 - 0.5 * 0.3 )$$

$$e_y = \beta * P * (0.75 * R + 0.2 * D_i) / f = 3.051 \text{ mm}$$

$$e_y = 0.7894 * 0.3 * (0.75 * 1848 + 0.2 * 2303) / 143.3$$

The auxiliary values for  $\beta$  (X, Y, Z, N at the end of mask) have been calculated iteratively with the required thickness e.

$$e_b = (0.75 * R + 0.2 * D_i) * \left| \frac{P * (D_i/r)^{0.825}}{111 * f_b} \right|^{(2/3)} = 3.654$$

$$e_b = (0.75 * 1848 + 0.2 * 2303) * \left| \frac{0.3 * (2303 / 355.7)^{0.825}}{111 * 143.3} \right|^{(2/3)}$$

$$e = \text{Max}(e_b, e_y, e_s) = \text{Max}(3.654, 3.051, 1.935) = 3.654$$

The strength condition is **valid** :

$$e_a = 3.654 \geq 3.654 = e$$

The strength condition is **valid** :

$$\text{Max}(0.06 * D_i, 2 * e_a) \leq r \leq D_i / 5$$

$$\text{Max}(138.2, 7.308) \leq 355.7 \leq 460.5$$

$$D_e / 1000 \leq e_a \leq 0.08 * D_e, \quad 2.31 \leq 3.654 \leq 184.8$$

$$R = 355.7 \leq 2310 = D_e$$



**— Rating of the permissible pressure**

---

$$P_s = 2 * f * Z * e_a / ( R + 0.5 * e_a ) = 0.5663$$

$$P_s = 2 * 143.3 * 1 * 3.654 / ( 1848 + 0.5 * 3.654 )$$

$$P_y = f * e_a / [ \beta * ( 0.75 * R + 0.2 * D_i ) ] = 0.3593$$

$$P_y = 143.3 * 3.654 / [ 0.7894 * ( 0.75 * 1848 + 0.2 * 2303 ) ]$$

$$P_b = 111 * f_b * [ e_a / ( 0.75 * R + D_i / 5 ) ]^{1.5} * ( r / D_i )^{0.825} = 0.3$$

$$P_b = 111 * 143.3 * [ 3.654 / ( 3 * 1848 / 4 + 2303 / 5 ) ]^{1.5} * ( 355.7 / D_i )^{0.825}$$

$$P_{max} = \min(P_b, P_y, P_s) = \max( 0.3, 0.3593, 0.5663 ) = 0.3$$

$$\text{Parameter: } Y = 0.001977, Z = 2.704, X = 0.1545, N = 0.8447$$

$$\text{Parameter: } \beta_{0.06} = 1.665, \beta_{0.1} = 1.102, \beta_{0.2} = 0.528$$

$$\beta = 0.7894$$

---



**07 EN08 B.6.3**

**Shells under external pressure DIN EN 13445-3/7 edition 2003-11 (state Nov.2005)**

**Spherical shells acc. to 8.7.1**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	1 (0,1)
EN 14025: Tanks for the transport of dangerous goods, section 6.4		
Load case: Operation = 1 / Test = 2	lc	1
Safety factor acc. to section 8.4.4	S	<b>1.5</b>
Calculation temperature	t	100 °C
Calculation pressure	P	3 bar
Final wall thickness with allowances	en	8 mm
Mean radius of the shell	R	1848 mm

**Material properties of the spherical shell:**

Material designation	Number	1.4404 (H)
Poisson's ratio	nu	0.3
Austenitic steel (1=yes, 2=no)		1
Wall thinning allowance	δe	0 mm
Corrosion allowance	c	0 mm
Thinning allowance during manufacturing	δm	0 mm
Sum of allowances	Σ(δ)	<b>0</b> mm
Strength acc. to specification (Re, Rp, Rm)	K	<b>430</b>
Safety factor according to section 8.4.4	S	<b>1.5</b>
Modulus of elasticity	E	194000 MPa
0.2% proof stress at operation temperature	Rp02	166 N/mm <sup>2</sup>
0.2% proof stress at room temperature	Rp02p	220 MPa
allowable elastic limit (Rpx, Rpx/1.25)	σe	<b>132.8</b> N/mm <sup>2</sup>
Curvature deviation greater than 30%? 1=yes, 2=no, Abw		2
based on a max. arc length of measuring range	Bog	
maximum radius of curvature	RKmax	mm

**Results:**

Calculation thickness without allowances	ea	<b>8</b> mm
Limit pressure for circumferential yield (8.7.1-1) py		<b>1.15</b> MPa
Theoretical instability pressure (8.7.1-2)	pm	<b>4.399</b> MPa
Ratio pm/py	pm/py	<b>3.826</b>
Ratio pr/py (Fig. 8.5-5)	pr/py	<b>0.4992</b>
allowable pressure (pr/S)	pzul	<b>0.3827</b> MPa

**Condition:** P = 0.3 < **0.3827** = pzul

The strength condition is **valid**  
for load case **Design**



**EN 14025: Tanks für die Beförderung gefährlicher Güter**  
**EN 14025: Tanks for the transport of dangerous goods**

**Module ADR**

$$p_y = 1.15 = 2 * \sigma_e * e_a / R = 2 * 132.8 * 8 / 1848 -$$

$$p_m = 4.399 = 1.21 * E * e_a^2 / R^2 = 1.21 * 194000 * 8^2 / 1848^2$$

$$p_{zul} = \begin{cases} p_r/S = 0.574 / 1.5, & \text{shape deviation} < 30\% \\ p_r/S * (1.3 * R / R_{Kmax})^2 = 0.574 / 1.5 * (1.3 * 1848 / )^2 \end{cases}$$

Max. measuring length of curvature deviation acc. to 8.7.2:

$$B_{og} = = 2.4 * \sqrt{(e_a * R_{Kmax})} = 2.4 * \sqrt{( 8 * )}$$

**Vessel ends acc. to section 8.8:**

Semi-spherical ends shall be designed acc. to the rules for spheres.  
 The mean sphere radius for torispherical shells is R=crown outside radius  
 and for the stress calculation acc. 7.5.2 (inside pressure P<0 with  
 module EN07) holds N=1.  
 For semi-ellipsoidal ends the mean sphere radius is R=D<sup>2</sup>/(4h).



**08 EN08 B.6.4.2**

**Shells under external pressure DIN EN 13445-3/7 edition 2003-11 (state Nov.2005)**

**Cylindrical shells with light stiffeners according to section 8.5.3.6**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	1 (0,1)
EN 14025: Tanks for the transport of dangerous goods, section 6.4		
Load case: Operation = 1 / Test = 2		1
Safety factor according to section 8.4.4 (1.5, 1.1)S		1.1
Calculation temperature	t	100 °C
Calculation pressure	P	0.4 bar
Final wall thickness of cylinder with allowances	en	3.65 mm
Web thickness of a stiffener without allowances	ew	8 mm

**Material properties of the cylinder:**

Material designation	Number 1.4404 (H)	
Austenitic steel? yes=1, no=2		1
Poisson's ratio (e.g. =0.3)	nu	0.3
Wall thinning allowance	δe	0 mm
Corrosion allowance	c	0 mm
Thinning allowance during manufacturing	δm	0 mm
Total allowance	Σ(δ)	0 mm
Strength acc. specification (Re, Rp1, Rm)	RK	430
Modulus of elasticity	E	195000 MPa
0.2% proof stress at operation temperature	Rp02	166 N/mm <sup>2</sup>
0.2% proof stress at room temperature	Rp02p	220 MPa
Allowable elastic limit (Rp02, Rp02/1.25)	σe	132.8 N/mm <sup>2</sup>

**Material properties of the stiffener:**

Material designation	Number 1.4404 (H)	
Austenitic steel? yes=1, no=2		1
Modulus of elasticity	ES	195000 MPa
Poisson's ratio (e.g. =0.3)	nuS	0.3
0.2% proof stress at operation temperature	Rp02S	166 MPa
0.2% proof stress at room temperature	Rp02Sp	220 MPa
Allowable elastic limit (Rp02, Rp02/1.25)	σeL	132.8 N/mm <sup>2</sup>
Additional safety factor for cold or hot rolled steel (1,33 or 1,20)	Sf	1.33

Rem.:

**Definition of cylinder length according to Table 8.5-1:**

**a) Analysis of failure of a cylinder section according to 8.5.3.4:**

- (1) between stiffener and cylinder end,
- (2) between two stiffeners.

Please enter (1, 2) for the concerned section 1

*For a stiffener at the cylinder end, please specify the distance Ls' from the end, height h' of dished end, and profile centroid w1" , F. 8.5-6, 8.5-8*

$$L = ( Ls' - w1" ) + 0.4 * h' \quad (8.5.3-1)$$

$$L = ( 1132 - 0 ) + 0.4 * 591$$

Result for the unsupported shell length: L = 1368 mm



**EN 14025: Tanks für die Beförderung gefährlicher Güter**  
**EN 14025: Tanks for the transport of dangerous goods**

Module ADR

Please specify also the distance  $L_s''$  of two stiffeners, and the appropriate profile centroids  $w_2'$  and  $w_2''$  acc. to Fig. 8.5-8

$$L = L_s'' - w_2' - w_2'' \quad (8.5.3-2)$$

$$L = 1368 - 0 - 0$$

Result for the unsupported shell length:  $L = 1368$  mm

**b) Verification of the elastic stability of single stiffeners (8.5.3.6.2):**

(1) for the first or last stiffener

(2) for an intermediate stiffener

Please specify the type (1 or 2) of stiffener

For stiffeners at the cylinder end with values above

$$L_s = (L_s' + 0.4 \cdot h' + L_s'')/2 \quad (8.5.3-6)$$

$$L_s = (1132 + 0.4 \cdot 591 + 1368)/2$$

Result for the mean distance:  $L_s = 1368$  mm

Please specify the distance  $L_s'''$  of adjacent stiffeners

$$L_s = (L_s'' + L_s''')/2 \quad (8.5.3-7)$$

$$L_s = (1368 + 1368)/2$$

The mean distance results in:  $L_s = 1368$  mm

**c) Additional specifications for the whole cylinder (8.5.3.6.2):**

Please specify the cylinder length  $L_{cyl}$  and end height  $h''$  acc. Fig. 8.5-6

$$LH = (L_{cyl} + 0.4 \cdot h' + 0.4 \cdot h'') \quad (8.5.3-10)$$

$$LH = (5000 + 0.4 \cdot 591 + 0.4 \cdot 591)$$

Result for the total length of the cylinder:  $LH = 5473$  mm

**Examination of failure between stiffeners acc. to 8.5.3.4**

**Specification:**

Calculation thickness of cylinder without allowances	ea	3.65	mm
Mean radius of shell	R	1152	mm
Radius of stiffener centroid	R <sub>s</sub>	1127	mm
Cross sectional area of stiffener	AS	368	mm <sup>2</sup>
Width of a stiffener in contact with shell	w	8	mm

**Results:**

Wave number of buckling shape	ncyl	10	
Factor acc. to Eq. (8.5.3-19)	δ	0.01982	
Calculation parameter of Eq. (8.5.3-22)	G	0	
Calculation parameter of Eq. (8.5.3-21)	N	1	
Factor Gamma according to Eq. (8.5.3-16)	γ	0.4179	
Modified area of stiffener, (8.5.3-17)	A <sub>m</sub>	384.4	mm <sup>2</sup>
Calculation parameter acc. to (8.5.3-18)	B	0.8903	
Limit pressure for circumferential yield (8.5.3-15)	p <sub>y</sub>	0.4208	MPa
Unsupported shell length between stiffeners	L	1368	mm
Parameter $\pi^*R/L$	Z	2.644	
Circumferential strain at collapse	ε	0.000143	
Theoretical elastic buckling pressure (8.5.2-5)	p <sub>m</sub>	0.08804	MPa
Real buckling pressure (Fig. 8.5-5)	p <sub>r</sub>	0.04402	MPa
Allowable pressure (p <sub>r</sub> /S)	p <sub>zul</sub>	0.04002	MPa

**Condition (8.5.2-8)**  $P < p_r/S$  is: **valid**

Load case: **Design**



**Stability of a stiffened cylinder according to 8.5.3.6.2** —

**a) Elastic instability, Specification of the stiffener**

+1=internal, -1=external stiffener, please enter +1,-1		1	
Manufacturing safety factor of stiffener	Sf	1.33	
Cross sectional area of stiffener	AS	368	mm <sup>2</sup>
Area moment at stiffener centroid	IS	64891	mm <sup>4</sup>

**Results:**

Mean distance between the stiffeners (Table 8.5-1)	LS	1368	mm
Total length of the cylinder (Table 8.5-1)	LH	<b>5473</b>	mm
Number of circumferential buckling waves	n	<b>4</b>	
Factor according to Eq. (8.5.3-25)	β	<b>0.000046</b>	
Combined cross sectional area of stiffened shell	Ae	<b>731.4</b>	mm <sup>2</sup>
Calculation parameter	Xe	<b>14.32</b>	
Effective Length acc. to (8.5.3-34) (u=	Le	<b>99.57</b>	mm
x= <b>0.0507</b> , Y1= <b>1.565</b> , Y2= <b>1.2</b> , Y3= <b>0.7211</b> )			
Area moment of shell and stiffener	Ie	<b>178029</b>	mm <sup>4</sup>
Theoretical elastic buckling pressure	pg	<b>0.2778</b>	MPa

**Condition (8.5.3-31):**  $P < pg / (S * Sf)$  is: **valid**

**b) Maximum stress in the stiffener, additional specifications:**

Contact width of the stiffener	wi	8	mm
Outside radius of the stiffener	Rf	1104	mm

**Results**

Modified area of stiffener (8.5.3-17)	Am	<b>384.4</b>	mm <sup>2</sup>
Factor (8.5.3-19)	δ	<b>0.01982</b>	
Factor (8.5.3-49)	dquer	<b>35.34</b>	
Limit pressure for circumferential yield	pys	<b>0.9335</b>	MPa
Maximum stress in the stiffener (8.5.3-46)	σs	<b>128.1</b>	MPa

**Condition (8.5.3-50)**  $0 < \sigma_s < \sigma_{eL} =$  **132.8** is: **valid**

**Sideways tripping of stiffeners**

**a) Stiffener with rectangular profile? (1=yes, 2=no)**

Radial height of the profile	d	46	mm
Width of the profile	ew	8	mm

**b) Specifications for non-rectangular profile, Figs. 8.5-14 to 8.5-17**

Angle profile acc. to Fig. 8.5-16 (yes=1, no=2)			
Radial height of the web plate between flanges	d	46	mm
Web thickness of the stiffener	ew	8	mm
Thickness of the profile flange	ef		mm
Leg length of the profile flange	wf		mm
Shell outside radius to the web plate	ri		mm
Coefficient for non-rectangular profile	C		

Instability stress for sideways tripping	σi	<b>765.3</b>	MPa
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**Condition:**  $\sigma_i > \sigma_{eL}$  is **valid**

*For stiffeners with flange at the remote edge of the web plate:*

**Limit dimensions according to (8.5.3-63/64)**



**09 EN08 B.6.4.4**

**Shells under external pressure DIN EN 13445-3/7 edition 2003-11 (state Nov.2005)**

**Cylindrical shells with light stiffeners according to section 8.5.3.6**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	1 (0,1)
EN 14025: Tanks for the transport of dangerous goods, section 6.4		
Load case: Operation = 1 / Test = 2		1
Safety factor according to section 8.4.4 (1.5, 1.1)S		1.1
Calculation temperature	t	100 °C
Calculation pressure	P	0.4 bar
Final wall thickness of cylinder with allowances	en	3.65 mm
Web thickness of a stiffener without allowances	ew	8 mm

**Material properties of the cylinder:**

Material designation	Number 1.4404 (H)	
Austenitic steel? yes=1, no=2		1
Poisson's ratio (e.g. =0.3)	nu	0.3
Wall thinning allowance	δe	0 mm
Corrosion allowance	c	0 mm
Thinning allowance during manufacturing	δm	0 mm
Total allowance	Σ(δ)	0 mm
Strength acc. specification (Re, Rp1, Rm)	RK	430
Modulus of elasticity	E	195000 MPa
0.2% proof stress at operation temperature	Rp02	166 N/mm <sup>2</sup>
0.2% proof stress at room temperature	Rp02p	220 MPa
Allowable elastic limit (Rp02, Rp02/1.25)	σe	132.8 N/mm <sup>2</sup>

**Material properties of the stiffener:**

Material designation	Number 1.4404 (H)	
Austenitic steel? yes=1, no=2		1
Modulus of elasticity	ES	195000 MPa
Poisson's ratio (e.g. =0.3)	nuS	0.3
0.2% proof stress at operation temperature	Rp02S	166 MPa
0.2% proof stress at room temperature	Rp02Sp	220 MPa
Allowable elastic limit (Rp02, Rp02/1.25)	σeL	132.8 N/mm <sup>2</sup>
Additional safety factor for cold or hot rolled steel (1,33 or 1,20)	Sf	1.33

Rem.:

**Definition of cylinder length according to Table 8.5-1:**

**a) Analysis of failure of a cylinder section according to 8.5.3.4:**

- (1) between stiffener and cylinder end,
- (2) between two stiffeners.

Please enter (1, 2) for the concerned section 1

*For a stiffener at the cylinder end, please specify the distance Ls' from the end, height h' of dished end, and profile centroid w1" , F. 8.5-6, 8.5-8*

$$L = ( Ls' - w1" ) + 0.4 * h' \quad (8.5.3-1)$$

$$L = ( 1132 - 0 ) + 0.4 * 591$$

Result for the unsupported shell length: L = 1368 mm



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Module ADR

Please specify also the distance  $L_s''$  of two stiffeners, and the appropriate profile centroids  $w_2'$  and  $w_2''$  acc. to Fig. 8.5-8

$$L = L_s'' - w_2' - w_2'' \quad (8.5.3-2)$$

$$L = 1368 - 0 - 0$$

Result for the unsupported shell length:  $L = 1368$  mm

**b) Verification of the elastic stability of single stiffeners (8.5.3.6.2):**

(1) for the first or last stiffener

(2) for an intermediate stiffener

Please specify the type (1 or 2) of stiffener 1

For stiffeners at the cylinder end with values above

$$L_s = (L_s' + 0.4 \cdot h' + L_s'')/2 \quad (8.5.3-6)$$

$$L_s = (1132 + 0.4 \cdot 591 + 1368)/2$$

Result for the mean distance:  $L_s = 1368$  mm

Please specify the distance  $L_s'''$  of adjacent stiffeners

$$L_s = (L_s'' + L_s''')/2 \quad (8.5.3-7)$$

$$L_s = (1368 + 1132)/2$$

The mean distance results in:  $L_s = 1250$  mm

**c) Additional specifications for the whole cylinder (8.5.3.6.2):**

Please specify the cylinder length  $L_{cyl}$  and end height  $h''$  acc. Fig. 8.5-6

$$LH = (L_{cyl} + 0.4 \cdot h' + 0.4 \cdot h'') \quad (8.5.3-10)$$

$$LH = (5000 + 0.4 \cdot 591 + 0.4 \cdot 591)$$

Result for the total length of the cylinder:  $LH = 5473$  mm

**Examination of failure between stiffeners acc. to 8.5.3.4**

**Specification:**

Calculation thickness of cylinder without allowances	ea	3.65	mm
Mean radius of shell	R	1152	mm
Radius of stiffener centroid	R <sub>s</sub>	1127	mm
Cross sectional area of stiffener	AS	368	mm <sup>2</sup>
Width of a stiffener in contact with shell	w	8	mm

**Results:**

Wave number of buckling shape	ncyl	10	
Factor acc. to Eq. (8.5.3-19)	δ	0.01982	
Calculation parameter of Eq. (8.5.3-22)	G	0	
Calculation parameter of Eq. (8.5.3-21)	N	1	
Factor Gamma according to Eq. (8.5.3-16)	γ	0.4179	
Modified area of stiffener, (8.5.3-17)	A <sub>m</sub>	384.4	mm <sup>2</sup>
Calculation parameter acc. to (8.5.3-18)	B	0.8903	
Limit pressure for circumferential yield (8.5.3-15)	p <sub>y</sub>	0.4208	MPa
Unsupported shell length between stiffeners	L	1368	mm
Parameter $\pi \cdot R/L$	Z	2.644	
Circumferential strain at collapse	ε	0.000143	
Theoretical elastic buckling pressure (8.5.2-5)	p <sub>m</sub>	0.08804	MPa
Real buckling pressure (Fig. 8.5-5)	p <sub>r</sub>	0.04402	MPa
Allowable pressure (p <sub>r</sub> /S)	p <sub>zul</sub>	0.04002	MPa

**Condition (8.5.2-8)**  $P < p_r/S$  is: **valid**

Load case: **Design**



**Stability of a stiffened cylinder according to 8.5.3.6.2** —

**a) Elastic instability, Specification of the stiffener**

+1=internal, -1=external stiffener, please enter +1,-1		1	
Manufacturing safety factor of stiffener	Sf	1.33	
Cross sectional area of stiffener	AS	368	mm <sup>2</sup>
Area moment at stiffener centroid	IS	64891	mm <sup>4</sup>

**Results:**

Mean distance between the stiffeners (Table 8.5-1)	LS	<b>1368</b>	mm
Total length of the cylinder (Table 8.5-1)	LH	<b>5473</b>	mm
Number of circumferential buckling waves	n	<b>4</b>	
Factor according to Eq. (8.5.3-25)	β	<b>0.000046</b>	
Combined cross sectional area of stiffened shell	Ae	<b>731.4</b>	mm <sup>2</sup>
Calculation parameter	Xe	<b>14.32</b>	
Effective Length acc. to (8.5.3-34) (u=	Le	<b>99.57</b>	mm
x= <b>0.0507</b> , Y1= <b>1.565</b> , Y2= <b>1.2</b> , Y3= <b>0.7211</b> )			
Area moment of shell and stiffener	Ie	<b>178029</b>	mm <sup>4</sup>
Theoretical elastic buckling pressure	pg	<b>0.2778</b>	MPa

**Condition (8.5.3-31):**  $P < pg / (S * Sf)$  is: **valid**

**b) Maximum stress in the stiffener, additional specifications:**

Contact width of the stiffener	wi	8	mm
Outside radius of the stiffener	Rf	1104	mm

**Results**

Modified area of stiffener (8.5.3-17)	Am	<b>384.4</b>	mm <sup>2</sup>
Factor (8.5.3-19)	δ	<b>0.01982</b>	
Factor (8.5.3-49)	dquer	<b>35.34</b>	
Limit pressure for circumferential yield	pys	<b>0.9335</b>	MPa
Maximum stress in the stiffener (8.5.3-46)	σs	<b>128.1</b>	MPa

**Condition (8.5.3-50)**  $0 < \sigma_s < \sigma_{eL} =$  **132.8** is: **valid**

**Sideways tripping of stiffeners**

**a) Stiffener with rectangular profile? (1=yes, 2=no)**

Radial height of the profile	d	46	mm
Width of the profile	ew	8	mm

**b) Specifications for non-rectangular profile, Figs. 8.5-14 to 8.5-17**

Angle profile acc. to Fig. 8.5-16 (yes=1, no=2)			
Radial height of the web plate between flanges	d	46	mm
Web thickness of the stiffener	ew	8	mm
Thickness of the profile flange	ef		mm
Leg length of the profile flange	wf		mm
Shell outside radius to the web plate	ri		mm
Coefficient for non-rectangular profile	C		

Instability stress for sideways tripping	σi	<b>765.3</b>	MPa
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**Condition:**  $\sigma_i > \sigma_{eL}$  is **valid**

*For stiffeners with flange at the remote edge of the web plate:*

**Limit dimensions according to (8.5.3-63/64)**



**10 EN08 B.6.5**

**Shells under external pressure DIN EN 13445-3/7 edition 2003-11 (state Nov.2005)**

**Spherical shells acc. to 8.7.1**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	1 (0,1)
EN 14025: Tanks for the transport of dangerous goods, section 6.4		
Load case: Operation = 1 / Test = 2	lc	1
Safety factor acc. to section 8.4.4	S	1.1
Calculation temperature	t	100 °C
Calculation pressure	P	0.4 bar
Final wall thickness with allowances	en	3.65 mm
Mean radius of the shell	R	1848 mm

**Material properties of the spherical shell:**

Material designation	Number	1.4404 (H)
Poisson's ratio	nu	0.3
Austenitic steel (1=yes, 2=no)		1
Wall thinning allowance	$\delta_e$	0 mm
Corrosion allowance	c	0 mm
Thinning allowance during manufacturing	$\delta_m$	0 mm
Sum of allowances	$\Sigma(\delta)$	0 mm
Strength acc. to specification (Re, Rp, Rm)	K	430
Safety factor according to section 8.4.4	S	1.1
Modulus of elasticity	E	194000 MPa
0.2% proof stress at operation temperature	Rp02	166 N/mm <sup>2</sup>
0.2% proof stress at room temperature	Rp02p	220 MPa
allowable elastic limit (Rpx, Rpx/1.25)	$\sigma_e$	132.8 N/mm <sup>2</sup>
Curvature deviation greater than 30%? 1=yes, 2=no, Abw		2
based on a max. arc length of measuring range	Bog	
maximum radius of curvature	RKmax	mm

**Results:**

Calculation thickness without allowances	ea	3.65 mm
Limit pressure for circumferential yield (8.7.1-1)	py	0.5246 MPa
Theoretical instability pressure (8.7.1-2)	pm	0.9157 MPa
Ratio pm/py	pm/py	1.746
Ratio pr/py (Fig. 8.5-5)	pr/py	0.2889
allowable pressure (pr/S)	pzul	0.1378 MPa

**Condition:** P = 0.04 < 0.1378 = pzul

The strength condition is **valid**  
for load case **Design**



$$p_y = 0.5246 = 2 * \sigma_e * e_a / R = 2 * 132.8 * 3.65 / 1848 -$$

$$p_m = 0.9157 = 1.21 * E * e_a^2 / R^2 = 1.21 * 194000 * 3.65^2 / 1848^2$$

$$p_{zul} = \begin{cases} p_r/S = 0.1516 / 1.1, & \text{shape deviation} < 30\% \\ p_r/S * (1.3 * R / R_{Kmax})^2 = 0.1516 / (1.1 * (1.3 * 1848 / ))^2 \end{cases}$$

Max. measuring length of curvature deviation acc. to 8.7.2:

$$Bog = = 2.4 * \sqrt{(e_a * R_{Kmax})} = 2.4 * \sqrt{(3.65 * )}$$

**Vessel ends acc. to section 8.8:**

Semi-spherical ends shall be designed acc. to the rules for spheres.  
 The mean sphere radius for torispherical shells is R=crown outside radius  
 and for the stress calculation acc. 7.5.2 (inside pressure P<0 with  
 module EN07) holds N=1.  
 For semi-ellipsoidal ends the mean sphere radius is R=D<sup>2</sup>/(4h).



**11 EN09 B6.6 Betr.**

**Openings in spherical and cylindrical shells EN 13445-3/9, A5:2006D + EN14025:2008-08**

**9. Isolated openings in spherical and cylindrical shells**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	0 (0,1)
EN 13445-3: Unfired pressure vessels		
Load case: Operation = 1, test = 2		1
Calculation temperature	t	100 °C
Calculation pressure	P	0.3 MPa

<b>Material properties</b>	<b>shell</b>	<b>nozzle</b>	<b>reinforcement</b>
Material designation	1.4404 (H)	1.4404 (H)	
Thickness allowance $\delta_e$	0 mm	0 mm	mm
Corrosion allowance c	0 mm	0 mm	mm
Manufacturing allowance	0 mm	0 mm	0 mm
Total allowance $\Sigma(\delta)$	0 mm	0 mm	mm
Strength $R_e, R_p, R_m$ K	430 MPa	430 MPa	MPa
Safety factor S	3	3	
Allowable stress f	143.3 MPa	143.3 MPa	MPa
Weld factor 9.5.2.3	1	1	
Remark:			

**Geometry of shell:**

Shell: Cylinder=1; sphere+semi-sphere+torispherical=2; elliptical=3; cone=4		1
Final wall thickness acc. drawing	ens	3.64 mm
Calculation thickness without allowance	eas	3.64 mm
Reduced calculation thickness without all. *)	ecs	3.64 mm
Outside diameter of shell	De	2307 mm
Actual length	ls	500 mm
Conical shell: semi-apex angle	$\alpha$	0 °
Elliptical shell: internal height	h	mm

\*)eas=ecs must satisfy the strength condition: ecs>required thickness

**Geometry of opening:**

Type of nozzle: without=1, set-in=2, set-on=3		
reinforcement ring=4, extruded=5		2
Orientation of sectional cut: axial=1 (cylinder) lateral=2 (sphere, cylinder)		1
Outside diameter of opening, nozzle or ring	d, deb	510 mm
Final nozzle (ring) thickness acc. drawing	ev, lr	5 mm
Application acc. 9.4.6: Fatigue=1, creep range=2, other=3		1
External cover (1=yes, 2=no)		1 (1,2)
Length of nozzle extension outside the shell	lb1	150 mm
Length of nozzle extension inside the shell	lbi	50 mm
Insertion length for partial penetration	lbp	3.64 mm
Reinforcement ring: Final axial length	ear	0 mm
Reinforcement ring: Radial thickness	lr	mm
Oblique nozzle: axial inclination angle	$\phi_a$	0 °
Oblique nozzle: circumferent. inclination angle	$\phi_u$	0 °

**Geometry of reinforcement:**

Final thickness	enp	0 mm
Width of reinforcement	lp	0 mm



**Results**

Allowable pressure ( $P = 0.3 \leq P_{max}$ )	$P_{max}$	<b>0.4367</b>	MPa
Pressure loaded area of shell	$A_{ps}$	<b>398557</b>	mm <sup>2</sup>
Pressure loaded area of nozzle	$A_{pb}$	<b>38410</b>	mm <sup>2</sup>
Additional pressure loaded area of oblique nozzle	$A_{p\phi}$	<b>0</b>	mm <sup>2</sup>
Cross-sectional area of fillet weld	$A_{fw}$	<b>0</b>	mm <sup>2</sup>

**Shell:**

Inside radius	$ris$	1150	mm
Maximum supporting length	$l_{so}$	<b>91.57</b>	mm
Supporting length of cylindrical connection	$l_{cyl}$	<b>91.57</b>	mm
Effective supporting length $Min(l_s, l_{so})$	$l's$	<b>91.57</b>	mm
Cross-sectional area of shell	$A_{fs}$	<b>333.3</b>	mm <sup>2</sup>

**Nozzle:**

Accountable wall thickness acc. 9.4.6	$eb$	<b>5</b>	mm
Calculation thickness without allowances	$eab$	<b>5</b>	mm
Max. supporting length of nozzle outside shell	$l_{bo}$	<b>50.25</b>	mm
Max. supporting length of nozzle inside shell	$l_{bo}/2$	<b>25.12</b>	mm
Reduced nozzle length outside shell $Min(l_b, l_{bo})$	$l'b$	150	mm
Red. nozzle length inside shell $Min(l_{bi}, l_{bo}/2)$	$l'bi$	46.36	mm
Reduced stress, $Min(f_s, f_b)$	$f_{ob}$	<b>143.3</b>	MPa
Cross-sectional area of nozzle	$A_{fb}$	<b>1000</b>	mm <sup>2</sup>
Adapted penetration length $Min(l_{bp}, e_{as})$	$e's$	<b>3.64</b>	mm
Inside diameter of nozzle	$d_{ib}$	<b>500</b>	mm
Outside radius of nozzle or opening	$a$	<b>255</b>	mm
Mean thickness of ring reinforcem. (iterative)	$e_{ams}$	0	mm
Accountable reinforcement width of ring	$l_0$		mm
Accountable axial ring length (9.5-44)	$er$		mm

**Reinforcement:**

Final thickness without allowances	$e_{ap}$	<b>0</b>	mm
Reduced thickness $Min. (e_{ap}, e_{as})$	$ep$	<b>0</b>	mm
Reduced width $Min. (l_p, l_{so})$	$l'p$	<b>0</b>	mm
Cross-sectional area	$A_{fp}$	<b>0</b>	mm <sup>2</sup>
Reduced allowable stress $Min(f_s, f_p)$	$f_{op}$	<b>0</b>	MPa

**Geometrical condition for openings:**

9.4.5 Shell without nozzle:	$d/(2*ris) =$	<b>0.2174</b>	$\leq$	0.5
9.4.5 Spheres+domed heads:	$d/De, d_{ib}/De$ or $d_{ir}/De =$	<b>0.2174</b>	$\leq$	0.6
9.4.5 Cylinder with nozzle:	$d/(2*ris) =$	<b>0.2174</b>	$\leq$	1
9.4.6 Reduced nozzle thickness:*)	$(e_v - c)/e_{as} =$	<b>1.374</b>	$\leq$	<b>2</b>
9.4.6 Max. nozzle thickness (fatigue):	$e_{ab}/e_{as} =$	<b>1.374</b>	$\leq$	<b>3</b>

\*) Only for creep range or fatigue

Load case	<b>Operation</b>
Application case	<b>Fatigue</b>
Shell type	<b>Cylinder</b>
Type of nozzle	<b>Set-in nozzle</b>
Orientation of section	<b>longitudinal</b>
The strength condition is	<b>valid</b>
The geometrical conditions are	<b>valid</b>



— **Additional results for openings close to discontinuities acc. 9.7** —

**9.7.2.1 Permissible distance  $w_{min}$  between opening in cylindrical shell and:**

- a) dished/flat end, reducer, flange  $w_{min}$  **18.31** mm
- b) small conical end, convex shell, branch  $w_{min}$  **91.57** mm
- c) expansion joint  $w_{min}$  **45.79** mm

**9.7.2.2 Permissible distance  $w_{min}$  between opening in conical shell and:**

- a) Cylindrical shell at wide end  $w_{min}$  **18.31** mm
- b) Cylindrical shell at small end  $w_{min}$  **91.57** mm

with a connection diameter  $D_c =$  **2304** mm  
 and a thickness  $e_1$  (or  $e_2$  acc. Fig. 9.7-10) **3.64** mm

**9.7.2.3 Permissible distance  $w_{min}$  between opening in domed and bolted head and a flange**  $w_{min}$  **18.31** mm

**9.7.2.4 Permissible distance  $w_{min}$  between opening in elliptical and torispherical heads and the knuckle ( $D_e/10$  acc. Fig.9.5-4)**  $w_{min} = 0$

Available distance (please specify a value)  $w$  mm

**9.5.2.2:**

Reinforcement dispensable if:  $d =$  **510**  $\leq$  **13.74**  $= 0.15 * l_{so}$  and  $w > w_{min}$

**9.7.3 Reduced distance from discontinuity:**

For  $w =$   $< w_p$ , the available support length of the reinforcement for the calculation  $l_s =$  **500** of the shell must be reduced.

The minimum distance  $w_p$  of the opening from discontinuities without influence on  $l_s$  and the reduced available support length  $Max(l_s)$

acc. 9.7.3 amount to:

	$w_p$	$Max(l_s)$
a) acc. to 9.7.2.1a), 9.7.2.2a), 9.7.2.3, 9.7.2.4	<b>91.57</b>	
b) acc. to 9.7.2.1b)	<b>183.1</b>	
b) acc. to 9.7.2.1c)	<b>137.4</b>	
c) acc. to 9.7.2.2b)	<b>183.1</b>	

— **Equations** —

$$l_{so} = \sqrt{(2 * r_{is} + e_{cs}) * e_{cs}} = \sqrt{(2 * 1150 + 3.64) * 3.64}$$

$$l_{so} = \mathbf{91.57} \text{ mm}$$

Cross-sectional area  $A_{fb}$  of the nozzle for type = **2**: (Type)

$$A_{fb} = e_b * (l'_b + l'_{bi} + e'_s) = \mathbf{5} * (150 + 46.36 + \mathbf{3.64}) \quad (2)$$

$$= e_b * l'_b = \mathbf{5} * 150 \quad (3)$$

$$= e_r * l_r = * \quad (4)$$

$$= e_b * l'_b = \mathbf{5} * 150 \text{ (Approximation)} \quad (5)$$

Cross-sectional area  $A_{fs}$  of the shell:

$$A_{fs} = e_{cs} * l'_s = \mathbf{3.64} * \mathbf{91.57} \quad (1, 2, 4, 5)$$

$$= e_{cs} * (e_b + l'_s) = \mathbf{3.64} * (5 + \mathbf{91.57}) \quad (3)$$

$$A_{fs} = \mathbf{333.3}, \quad A_{fb} = \mathbf{1000}, \quad A_{fw} = 0$$

$$A_{fp} = 0 = e_p * l'_p = 0 * 0$$



Pressure loaded area of nozzle

$$A_{pb} = 0.5 * d_i * (l'b + e_{as}) = 38410 \text{ mm}^2$$

$$= 0.5 * 510 * (150 + 3.64)$$

$$= 0 \text{ for Typ 1 and 4}$$

Additional pressure loaded area for oblique direction **longitudinal**

$$A_{p\phi} = (d_{ib}^2 * \tan(\phi)) / 2 = 0$$

$$= (500^2 * \tan(0)) / 2 \quad \text{(axial)}$$

$$= (500^2 * \tan(0)) / 2 \quad \text{(lateral)}$$

$$P \leq \frac{(A_{fs} + A_{fw}) * (f_s - 0.5 * P) + A_{fp} * (f_{op} - 0.5 * P) + A_{fb} * (f_{ob} - 0.5 * P)}{(A_{ps} + A_{pb})}$$

$$P \leq \left[ \frac{(333.3 + 0) * (143.3 - 0.5 * 0.3) + 0 * (0 - 0.5 * 0.3) + 1000 * (143.3 - 0.5 * 0.3)}{(398557 + 38410)} \right]$$

The strength condition is **valid** : Efficiency = **0.687** ≤ 1

— **Maximum permissible pressure** —

$$P_{max} = 0.4367 = \frac{(A_{fs} + A_{fw}) * f_s + A_{fb} * f_{ob} + A_{fp} * f_{op}}{(A_{ps} + A_{pb}) + 0.5 * (A_{fs} + A_{fw} + A_{fb} + A_{fp})}$$

$$P_{max} = \frac{(333.3 + 0) * 143.3 + 1000 * 143.3 + 0 * 0}{(398557 + 38410) + 0.5 * (333.3 + 0 + 1000 + 0)}$$



**12 EN09 B6.6 Prf.**

**Openings in spherical and cylindrical shells EN 13445-3/9, A5:2006D + EN14025:2008-08**

**9. Isolated openings in spherical and cylindrical shells**

Regulation (0=EN13445-3, 1=EN14025)	TFZ	0 (0,1)
EN 13445-3: Unfired pressure vessels		
Load case: Operation = 1, test = 2		2
Calculation temperature	t	100 °C
Calculation pressure	P	0.4 MPa

<b>Material properties</b>	<b>shell</b>	<b>nozzle</b>	<b>reinforcement</b>
Material designation	1.4404 (H)	1.4404 (H)	
Thickness allowance $\delta_e$	0 mm	0 mm	mm
Corrosion allowance c	0 mm	0 mm	mm
Manufacturing allowance	0 mm	0 mm	0 mm
Total allowance $\Sigma(\delta)$	0 mm	0 mm	mm
Tensile stress 20°C Rm	<b>530</b> MPa	<b>530</b> MPa	MPa
Proof stress 20°C Rp	<b>260</b> MPa	<b>260</b> MPa	MPa
$f = \text{Min}[Rm20/2, Rpe*3/4]$	<b>195</b> MPa	<b>195</b> MPa	MPa
Weld factor 9.5.2.3	1	1	

Remark:

**Geometry of shell:**

Shell: Cylinder=1; sphere+semi-sphere+torispherical=2; elliptical=3; cone=4		1
Final wall thickness acc. drawing	ens	3.64 mm
Calculation thickness without allowance	eas	<b>3.64</b> mm
Reduced calculation thickness without all. *)	ecs	<b>3.64</b> mm
Outside diameter of shell	De	<b>2307</b> mm
Actual length	ls	500 mm
Conical shell: semi-apex angle	$\alpha$	0 °
Elliptical shell: internal height	h	mm

\*)eas=ecs must satisfy the strength condition: ecs>required thickness

**Geometry of opening:**

Type of nozzle: without=1, set-in=2, set-on=3		
reinforcement ring=4, extruded=5		2
Orientation of sectional cut: axial=1 (cylinder) lateral=2 (sphere, cylinder)		1
Outside diameter of opening, nozzle or ring	d, deb	510 mm
Final nozzle (ring) thickness acc. drawing	ev, lr	5 mm
Application acc. 9.4.6: Fatigue=1, creep range=2, other=3		1
External cover (1=yes, 2=no)		1 (1,2)
Length of nozzle extension outside the shell	lb1	150 mm
Length of nozzle extension inside the shell	lbi	50 mm
Insertion length for partial penetration	lbp	<b>3.64</b> mm
Reinforcement ring: Final axial length	ear	0 mm
Reinforcement ring: Radial thickness	lr	mm
Oblique nozzle: axial inclination angle	$\phi_a$	0 °
Oblique nozzle: circumferent. inclination angle	$\phi_u$	0 °

**Geometry of reinforcement:**

Final thickness	enp	0 mm
Width of reinforcement	lp	0 mm



**Results**

Allowable pressure ( $P = 0.4 \leq P_{max}$ )	$P_{max}$	<b>0.5941</b>	MPa
Pressure loaded area of shell	$A_{ps}$	<b>398557</b>	mm <sup>2</sup>
Pressure loaded area of nozzle	$A_{pb}$	<b>38410</b>	mm <sup>2</sup>
Additional pressure loaded area of oblique nozzle	$A_{p\phi}$	<b>0</b>	mm <sup>2</sup>
Cross-sectional area of fillet weld	$A_{fw}$	<b>0</b>	mm <sup>2</sup>

**Shell:**

Inside radius	$r_{is}$	1150	mm
Maximum supporting length	$l_{so}$	<b>91.57</b>	mm
Supporting length of cylindrical connection	$l_{cyl}$	<b>91.57</b>	mm
Effective supporting length $\text{Min}(l_s, l_{so})$	$l's$	<b>91.57</b>	mm
Cross-sectional area of shell	$A_{fs}$	<b>333.3</b>	mm <sup>2</sup>

**Nozzle:**

Accountable wall thickness acc. 9.4.6	$e_b$	<b>5</b>	mm
Calculation thickness without allowances	$e_{ab}$	<b>5</b>	mm
Max. supporting length of nozzle outside shell	$l_{bo}$	<b>50.25</b>	mm
Max. supporting length of nozzle inside shell	$l_{bo}/2$	<b>25.12</b>	mm
Reduced nozzle length outside shell $\text{Min}(l_b, l_{bo})$	$l'b$	150	mm
Red. nozzle length inside shell $\text{Min}(l_{bi}, l_{bo}/2)$	$l'bi$	46.36	mm
Reduced stress, $\text{Min}(f_s, f_b)$	$f_{ob}$	<b>195</b>	MPa
Cross-sectional area of nozzle	$A_{fb}$	<b>1000</b>	mm <sup>2</sup>
Adapted penetration length $\text{Min}(l_{bp}, e_{as})$	$e's$	<b>3.64</b>	mm
Inside diameter of nozzle	$d_{ib}$	<b>500</b>	mm
Outside radius of nozzle or opening	$a$	<b>255</b>	mm
Mean thickness of ring reinforcement. (iterative)	$e_{ams}$	0	mm
Accountable reinforcement width of ring	$l_0$		mm
Accountable axial ring length (9.5-44)	$e_r$		mm

**Reinforcement:**

Final thickness without allowances	$e_{ap}$	<b>0</b>	mm
Reduced thickness $\text{Min.}(e_{ap}, e_{as})$	$e_p$	<b>0</b>	mm
Reduced width $\text{Min.}(l_p, l_{so})$	$l'p$	<b>0</b>	mm
Cross-sectional area	$A_{fp}$	<b>0</b>	mm <sup>2</sup>
Reduced allowable stress $\text{Min}(f_s, f_p)$	$f_{op}$	<b>0</b>	MPa

**Geometrical condition for openings:**

9.4.5 Shell without nozzle:	$d/(2 \cdot r_{is}) =$	<b>0.2174</b>	$\leq$	0.5
9.4.5 Spheres+domed heads:	$d/D_e, d_{ib}/D_e$ or $d_{ir}/D_e =$	<b>0.2174</b>	$\leq$	0.6
9.4.5 Cylinder with nozzle:	$d/(2 \cdot r_{is}) =$	<b>0.2174</b>	$\leq$	1
9.4.6 Reduced nozzle thickness:*)	$(e_v - c)/e_{as} =$	<b>1.374</b>	$\leq$	<b>2</b>
9.4.6 Max. nozzle thickness (fatigue):	$e_{ab}/e_{as} =$	<b>1.374</b>	$\leq$	<b>3</b>

\*) Only for creep range or fatigue

Load case	<b>Test</b>
Application case	<b>Fatigue</b>
Shell type	<b>Cylinder</b>
Type of nozzle	<b>Set-in nozzle</b>
Orientation of section	<b>longitudinal</b>
The strength condition is	<b>valid</b>
The geometrical conditions are	<b>valid</b>



— **Additional results for openings close to discontinuities acc. 9.7** —

**9.7.2.1 Permissible distance  $w_{min}$  between opening in cylindrical shell and:**

- a) dished/flat end, reducer, flange  $w_{min}$  **18.31** mm
- b) small conical end, convex shell, branch  $w_{min}$  **91.57** mm
- c) expansion joint  $w_{min}$  **45.79** mm

**9.7.2.2 Permissible distance  $w_{min}$  between opening in conical shell and:**

- a) Cylindrical shell at wide end  $w_{min}$  **18.31** mm
- b) Cylindrical shell at small end  $w_{min}$  **91.57** mm

with a connection diameter  $D_c =$  **2304** mm  
 and a thickness  $e_1$  (or  $e_2$  acc. Fig. 9.7-10) **3.64** mm

**9.7.2.3 Permissible distance  $w_{min}$  between opening in domed and bolted head and a flange**  $w_{min}$  **18.31** mm

**9.7.2.4 Permissible distance  $w_{min}$  between opening in elliptical and torispherical heads and the knuckle ( $D_e/10$  acc. Fig.9.5-4)**  $w_{min} = 0$

Available distance (please specify a value)  $w$  mm

**9.5.2.2:**

Reinforcement dispensable if:  $d =$  **510**  $\leq$  **13.74**  $= 0.15 * l_{so}$  and  $w > w_{min}$

**9.7.3 Reduced distance from discontinuity:**

For  $w =$   $< w_p$ , the available support length of the reinforcement for the calculation  $l_s =$  **500** of the shell must be reduced.

The minimum distance  $w_p$  of the opening from discontinuities without influence on  $l_s$  and the reduced available support length  $Max(l_s)$

acc. 9.7.3 amount to:

	<b><math>w_p</math></b>	<b>Max (<math>l_s</math>)</b>
a) acc. to 9.7.2.1a), 9.7.2.2a), 9.7.2.3, 9.7.2.4	<b>91.57</b>	
b) acc. to 9.7.2.1b)	<b>183.1</b>	
b) acc. to 9.7.2.1c)	<b>137.4</b>	
c) acc. to 9.7.2.2b)	<b>183.1</b>	

— **Equations** —

$$l_{so} = \sqrt{(2 * r_{is} + e_{cs}) * e_{cs}} = \sqrt{(2 * 1150 + 3.64) * 3.64}$$

$$l_{so} = \mathbf{91.57} \text{ mm}$$

Cross-sectional area  $A_{fb}$  of the nozzle for type = **2**: (Type)

$$A_{fb} = e_b * (l'_b + l'_{bi} + e'_s) = \mathbf{5} * (150 + 46.36 + \mathbf{3.64}) \quad (2)$$

$$= e_b * l'_b = \mathbf{5} * 150 \quad (3)$$

$$= e_r * l_r = * \quad (4)$$

$$= e_b * l'_b = \mathbf{5} * 150 \text{ (Approximation)} \quad (5)$$

Cross-sectional area  $A_{fs}$  of the shell:

$$A_{fs} = e_{cs} * l'_s = \mathbf{3.64} * \mathbf{91.57} \quad (1, 2, 4, 5)$$

$$= e_{cs} * (e_b + l'_s) = \mathbf{3.64} * (5 + \mathbf{91.57}) \quad (3)$$

$$A_{fs} = \mathbf{333.3}, \quad A_{fb} = \mathbf{1000}, \quad A_{fw} = 0$$

$$A_{fp} = 0 = e_p * l'_p = 0 * 0$$



Pressure loaded area of nozzle

$$A_{pb} = 0.5 * d_i * (l'b + e_{as}) = 38410 \text{ mm}^2$$

$$= 0.5 * 510 * (150 + 3.64)$$

$$= 0 \text{ for Typ 1 and 4}$$

Additional pressure loaded area for oblique direction **longitudinal**

$$A_{p\phi} = (d_{ib}^2 * \tan(\phi)) / 2 = 0$$

$$= (500^2 * \tan(0)) / 2 \quad \text{(axial)}$$

$$= (500^2 * \tan(0)) / 2 \quad \text{(lateral)}$$

$$P \leq \frac{(A_{fs} + A_{fw}) * (f_s - 0.5 * P) + A_{fp} * (f_{op} - 0.5 * P) + A_{fb} * (f_{ob} - 0.5 * P)}{(A_{ps} + A_{pb})}$$

$$P \leq \left[ \frac{(333.3 + 0) * (195 - 0.5 * 0.4) + 0 * (0 - 0.5 * 0.4) + 1000 * (195 - 0.5 * 0.4)}{(398557 + 38410)} \right]$$

The strength condition is **valid** : Efficiency = **0.6733** ≤ 1

— **Maximum permissible pressure** —

$$P_{max} = 0.5941 = \frac{(A_{fs} + A_{fw}) * f_s + A_{fb} * f_{ob} + A_{fp} * f_{op}}{(A_{ps} + A_{pb}) + 0.5 * (A_{fs} + A_{fw} + A_{fb} + A_{fp})}$$

$$P_{max} = \frac{(333.3 + 0) * 195 + 1000 * 195 + 0 * 0}{(398557 + 38410) + 0.5 * (333.3 + 0 + 1000 + 0)}$$



## 13 Zusammenfassung

### Documentation

Beispiel EN 14025 Anhang B, Vergleich Lauterbach-Berechnung

Berechnung nach EN14025 Abschnitt	Lauterbach Verfahrenstechnik
B.3 Mindestwanddicke nach ADR	
eT = 2.95 mm	eT = 2.949 mm
eC = 2.36 mm	eC = 2.359 mm
B.4 Gleichwertige Wanddicke	
e1 = 3.64 mm	e1 = 3.635 mm
B.5.1: Prüfdruck Zylinder	
erforderliche Dicke e = 2.95 mm	e = 2.953 mm
B.5.2: Prüfdruck Korbbojen	
erforderliche Dicke e = 3.6 mm	e = 3.602 mm
ey = 2.91 (mit ev=5mm)	ey = 2.988 (iterativ mit ey)
B.5.3: Prüfdruck Trennwand e=8mm	
zulässiger Prüfdruck P = 0.6 MPa	Pzul = 0.5994 MPa
B.6.1: Betriebsdruck 3bar Zylinder	
erforderliche Dicke e = 3.02 mm	e = 3.013 mm
B.6.2: Betriebsdruck 3bar Korbbojen	
erforderliche Dicke emin = 3.65 mm	emin = 3.654 mm (iterativ)
B.6.3: Betriebsdruck 3bar Trennwand e=8mm	
zulässiger Betriebsdruck p = 0.383 MPa	Pzul = 0.3827 MPa
B.6.4.2 wie B.6.4.3	
B.6.4.3: Versagen zwischen Versteifungen	
zulässiger Außendruck p=0.04 MPa	pzul = 0.04002 MPa
B.6.4.4: Versteifter Zylinder	
zulässiger Außendruck p=0.190 MPa	pzul = 0.1899 MPa (8.5.3-31)
Spannung in der Versteifung SigS = 129.1	SigS = 128.1
Seitliche Auslenkung:	
Sigi/4 = 766.72/4 > 0.04*132.8/0.932	765.3/4 > 0.04*132.8/0.9335
B.6.5: Außendruck 0.4 bar Kugelschale	
pzul = 0.138 MPa	pzul = 0.1378 MPa
B.6.6 Betriebsdruck Ausschnitt	
131 200 / 190 663 = 0.688 < 1	Auslastung = 0.687 < 1
B.6.6: Prüfdruck Ausschnitt	
174 933 / 259 995 = 0.673 < 1	Auslastung = 0.6733 < 1



## 14 Summary

### Documentation

Example EN 14025 Appendix B, Comparison with calculation by Lauterbach

Calculation acc. EN14025 section	Lauterbach Verfahrenstechnik
B.3 Minimum thickness acc. to ADR eT = 2.95 mm eC = 2.36 mm	eT = 2.949 mm eC = 2.359 mm
B.4 Equivalent thickness e1 = 3.64 mm	e1 = 3.635 mm
B.5.1: Testing pressure cylinder required thickness e = 2.95 mm	e = 2.953 mm
B.5.2: Test pressure Korbbogen required thickness e = 3.6 mm ey = 2.91 (with ev=5mm)	e = 3.602 mm ey = 2.988 (iter. with ey)
B.5.3: Test pressure baffle e=8mm allowable pressure P = 0.6 MPa	Pzul = 0.5994 MPa
B.6.1: Operation pressure 3bar Cylinder required thickness e = 3.02 mm	e = 3.013 mm
B.6.2: Operation pressure 3bar Korbbogen required thickness emin = 3.65 mm	emin = 3.654 mm
B.6.3: Operation pressure 3bar baffle e=8mm allowable pressure p = 0.383 MPa	Pzul = 0.3827 MPa
B.6.4.2 as B.6.4.3 B.6.4.3: Failure between stiffeners allowable external pressure p=0.04 MPa	pzul = 0.04002 MPa
B.6.4.4: Stiffened cylinder allowable external pressure p=0.190 MPa Stress in stiffener SigS = 129.1 Sideways tripping: Sigi/4 = 766.72/4 > 0.04*132.8/0.932	pzul = 0.1899MPa (8.5.3-31) SigS = 128.1 765.3/4 > 0.04*132.8/0.9335
B.6.5: External pressure 0.4bar sphere pzul = 0.138 MPa	pzul = 0.1378 MPa
B.6.6 Operation pressure opening 131 200 / 190 663 = 0.688 < 1	efficiency = 0.687 < 1
B.6.6: Test pressure opening 174 933 / 259 995 = 0.673 < 1	efficiency = 0.6733 < 1