



BSI Standards Publication

Shell boilers

Part 3: Design and calculation for pressure parts

National foreword

This British Standard is the UK implementation of EN 12953-3:2016, incorporating corrigendum July 2024. It supersedes BS EN 12953-3:2002, which is withdrawn.

BSI, as a member of CEN, is obliged to publish EN 12953-3:2016 as a British Standard. However, attention is drawn to the fact that during the development of this European Standard, the UK committee voted against its approval as a European Standard.

The UK committee is concerned that Subclause 10.2.11.3 introduces requirements that are too restrictive. In their opinion, the principles included in Subclause 10.2.10.3 of BS EN 12953-3:2002 better reflect the design parameters currently used in the UK.

The UK participation in its preparation was entrusted to Technical Committee PVE/2, Water Tube And Shell Boilers.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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English Version

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European foreword

This document (EN 12953-3:2016) has been prepared by Technical Committee CEN/TC 269 “Shell and water-tube boilers”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2016, and conflicting national standards shall be withdrawn at the latest by November 2016.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 12953-3:2002.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

The informative Annex E lists the significant technical changes between this European Standard and the previous edition.

EN 12953, Shell boilers, consists of the following parts:

- *Part 1: General*
- *Part 2: Materials for pressure parts of boilers and accessories*
- *Part 3: Design and calculation for pressure parts*
- *Part 4: Workmanship and construction of pressure parts of the boiler*
- *Part 5: Inspection during construction, documentation and marking of pressure parts of the boiler*
- *Part 6: Requirements for equipment for the boiler*
- *Part 7: Requirements for firing systems for liquid and gaseous fuels for the boilers*
- *Part 8: Requirements for safeguards against excessive pressure*
- *Part 9: Requirements for limiting devices of the boiler and accessories*
- *Part 10: Requirements for feedwater and boiler water quality*
- *Part 11: Acceptance tests*
- *Part 12: Requirements for grate firing systems for solid fuels for the boiler*
- *Part 13: Operating instructions*
- *(CR 12953) Part 14: Guideline for involvement of an inspection body independent of the manufacturer*

Although these parts can be obtained separately, it should be recognized that the parts are interdependent. As such, the design and manufacture of shell boilers requires the application of more than one part in order for the requirements of the standard to be satisfactorily fulfilled.

EN 12953-3:2016 (E)

NOTE A “Boiler Helpdesk” has been established in CEN/TC 269 which may be contacted for any questions regarding the application of the European Standards series EN 12952 and EN 12953, see the following website: <http://www.boiler-helpdesk.din.de>

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1 Scope

This Part of this European Standard specifies requirements for the design and calculation of pressure parts of shell boilers as defined in EN 12953-1.

For other components such as water tube walls reference should be made to EN 12952 series.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1092-1:2007+A1:2013, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 1: Steel flanges*

EN 10160, *Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm (reflection method)*

EN 12952-3:2011, *Water-tube boilers and auxiliary installations — Part 3: Design and calculation for pressure parts of the boiler*

EN 12953-1:2012, *Shell boilers — Part 1: General*

EN 12953-2:2012, *Shell boilers — Part 2: Materials for pressure parts of boilers and accessories*

EN 12953-4:2002, *Shell boilers — Part 4: Workmanship and construction of pressure parts of the boiler*

EN 12953-5, *Shell boilers — Part 5: Inspection during construction, documentation and marking of pressure parts of the boiler*

EN 12953-6:2011, *Shell Boilers — Part 6: Requirements for equipment for the boiler*

EN 12953-10:2003, *Shell boilers — Part 10: Requirements for feedwater and boiler water quality*

EN 13445-3:2014, *Unfired pressure vessels — Part 3: Design*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12953-1:2012, EN 12953-6:2011 and the following apply.

3.1

branch

nozzle, stub, stand pipe

3.2

cold start

starting the boiler from ambient pressure at room temperature to normal operating condition

3.3

warm start

starting the boiler from the hot stand-by condition

3.4

seam

generic term for welded joints, welded seams or welds

4 Symbols and abbreviations

For the purposes of this standard, the symbols given in EN 12953-1:2012, Table 1 shall apply. Throughout this standard, additional terminology and symbols have been included where necessary to meet the requirements of the specific text concerned. It should also be noted that in some clauses the same additional symbol is used in different formulas to represent different terms. However, in all such cases, the special meaning of each symbol is indicated for each formula.

5 General

5.1 Boilers

The requirements in this standard shall apply to boilers as defined in EN 12953-1:2012 designed throughout under the conditions specified herein and which are to be operated under normal operation conditions, with feedwater and boiler water in accordance with EN 12953-10:2003, and under adequate supervision.

Where there are specified operation conditions such as e.g. severe cyclic service, this shall be taken into account in the design process.

The feed water entering a steam boiler or the return water entering a hot water boiler shall not impinge directly on the furnace.

No load cycle calculation shall be carried out if all the following requirements are satisfied:

- a) The number of start-ups from zero pressure to the foreseen operating pressure (full pressure cycles) is ≤ 1000 ;
- b) For material with specified yield strength at room temperature ≤ 295 MPa the number of partial pressure cycles in the range of $\Delta P = 20$ % of PS is $\leq 100\,000$ or, alternatively, in the range of $\Delta P = 40$ % of PS is $\leq 10\,000$;
- c) For material with specified yield strength at room temperature > 295 MPa the number of partial pressure cycles in the range of $\Delta P = 10$ % of PS is $\leq 100\,000$ or, alternatively, in the range of $\Delta P = 20$ % of PS is $\leq 10\,000$;
- d) The weld for set-in end plates to shell and/or to furnace shall be at least 10 % UT tested during construction.

Otherwise if the load cycle situation is more complicated a load cycle calculation shall be performed.

The requirements for the load cycle calculation are not applicable for the weld factor 0,7 (see 5.4).

5.2 Hot-water boilers

For directly fired hot-water boilers the difference between the outlet temperature and the inlet temperature should not exceed 50 K. If the difference between these two temperatures is greater than 50 K, either internal or external mixing devices shall be used to limit the differential temperature within the boiler to 50 K.

The difference between the saturation temperature corresponding to the maximum operating pressure, and the outlet temperature, should not normally exceed 80 K. If the difference is greater than 80 K, the distances in accordance with 10.1 shall be increased by 50 %. Furthermore the maximum heat input in accordance with Figure 1 shall be reduced by 20 %.

5.3 Main welds

The types of weld used in the design of the boiler shall be in accordance with EN 12953-4.

Non-destructive testing (NDT) shall be in accordance with the requirements of EN 12953-5. The design of the weld joints shall be such that the required NDT can be carried out.

5.4 Weld factor

The weld factors v used in the calculation of the pressure parts shall be either 1 or 0,85 or 0,7 depending on the extent of NDT.

The extent of NDT shall be in accordance with EN 12953-5.

A welding efficiency $v = 0,7$ is only acceptable, if an increased test pressure is used as given by Formula (1):

$$p_t = 2,2 p_c \frac{R_{p0,2 20}}{R_{p0,2 tc}} \cdot \frac{e_{cs} + c_2}{e_{cs}} \quad (1)$$

5.5 Thermal design of furnaces tubes

5.5.1 Design conditions

Burners with a fixed firing rate (also called on/off or single stage burners) shall not be used for heat inputs exceeding 1 MW per furnace.

Combustion shall be completed in the furnace.

Calculation temperature shall be in accordance with 6.1 e).

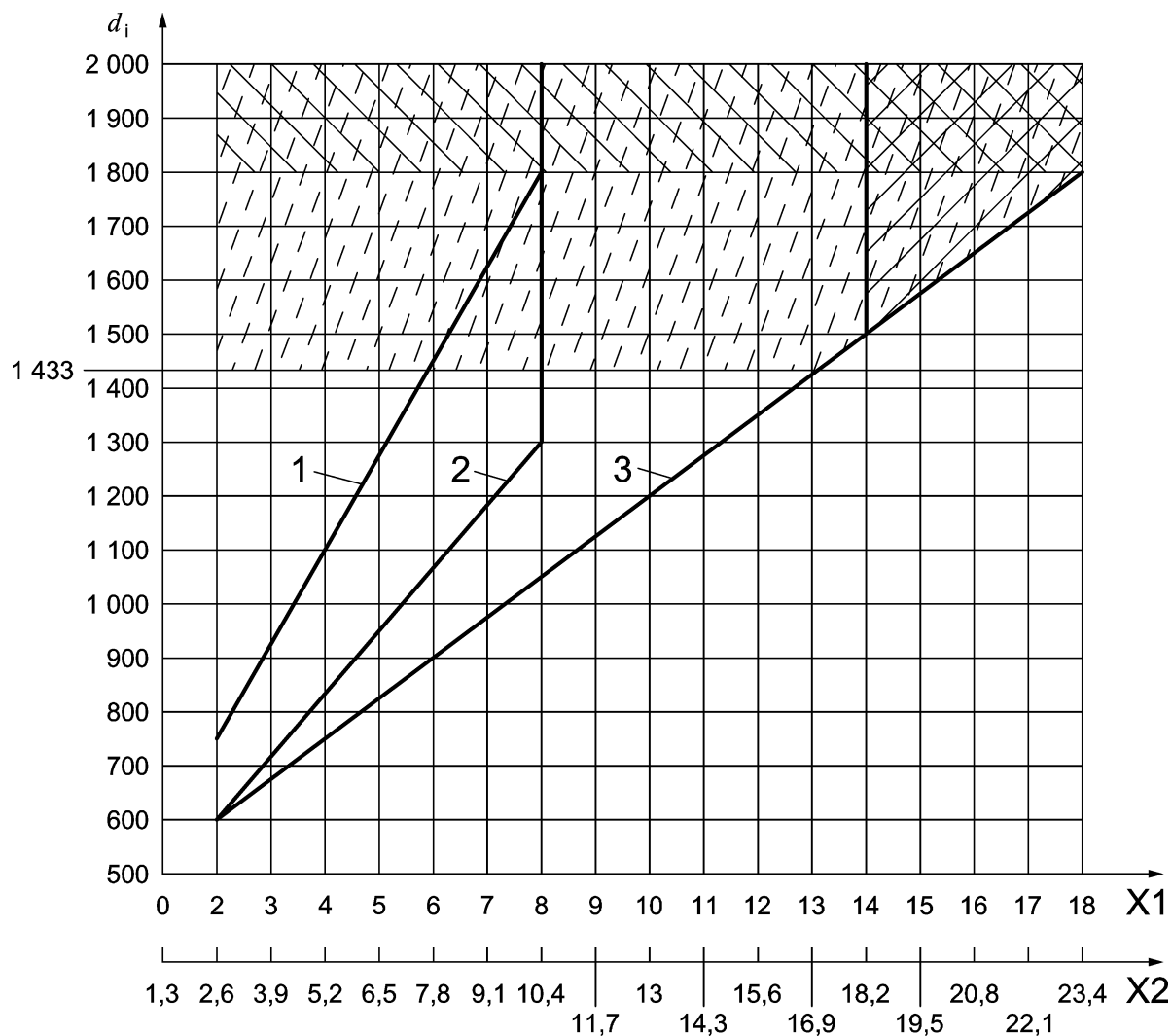
In order to ensure safe burner/boiler combinations with a heat input more than 2 MW, the minimum diameter of the furnace d_i shall not be less than the following values (see Figure 1):

- a) No 1 Material grade P265GH/P295GH: Coal firing (grate): $d_i = 400 + 175 * H$
- b) No 2 Material grade P265GH: Oil firing: $d_i = 365 + 117 * H$ Gas firing: $d_i = 365 + 90,4 * H$
- c) No 3 Material grade P295GH/P355GH: Oil firing: $d_i = 450 + 75 * H$ Gas firing: $d_i = 450 + 57,7 * H$

where:

d_i = inner diameter in mm for plain furnaces (with or without stiffeners or bowling hoops) or average diameter mm for corrugated furnaces (with or without stiffeners);

H = heat input in MW (product of the fuel flow rate and the lower calorific value; air preheating should be taken into account if the air temperature is greater than 100 °C).



Key

1 coal firing P265GH/P295GH

2 P265GH

3 P295GH / P355GH

d_i inner diameter for plain furnaces (with or without stiffeners or bowling hoops) or average diameter for corrugated furnaces (with or without stiffeners) [mm]

X1 heat input H_{oil} / H_{coal} [MW]

X2 heat input H_{gas} [MW]



temperature monitoring necessary if $d_i > 1800$ mm

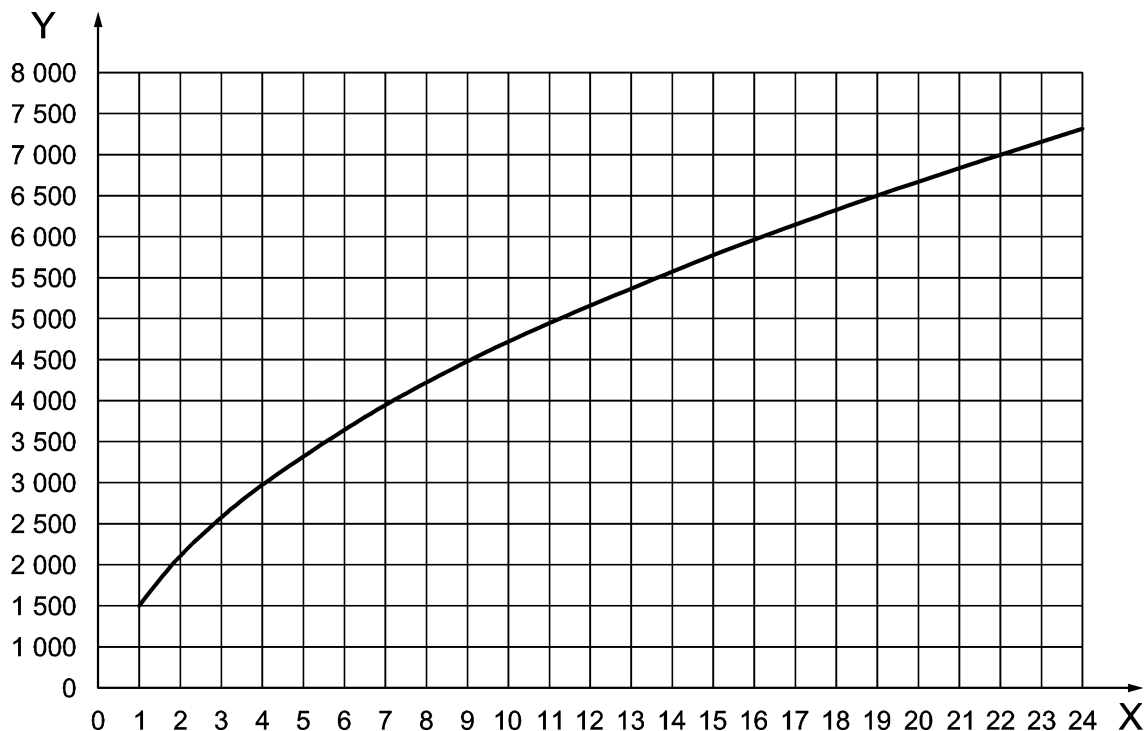


temperature monitoring necessary if $H_{oil} > 14$ MW respectively, $H_{gas} > 18,2$ MW



monitoring of operation conditions if $d_i > 1433$ mm

Figure 1 — Relation between heat input and inside diameter of the furnace d_i

**Key**

Y minimum furnace tube length [mm]

X heat input [MW]

Figure 2 — Relation between heat input and length of the furnace L **5.5.2 Furnace dimensions**

The minimum furnace length shall be determined either by using the Figure 2 or the Formula (2):

$$L [\text{mm}] = 150000 * (H [\text{MW}] / 10100)^{0.5} \quad (2)$$

If the furnace diameter is less than the minimum diameter (see Figure 1) or the furnace length is less than the min req. length (see Figure 2) the following conditions shall be fulfilled:

- Verification of heat flux and calculation temperature of furnace (e.g. according to 6.1 e)). Lower calculation temperatures than in Formula 12 shall not be used.
- Continuous monitoring of water quality (see EN 12953-6:2011, 4.8.2, 4.8.3 and 4.8.4)

If the furnace diameter is greater than 1800 mm the following conditions shall be fulfilled:

- A separate stress analysis of the furnace (e.g. by a suitable FEA calculation) is necessary to prove the factor of safety against deformation and rupture

5.5.3 Heat input

If the heat input is more than $H_{\text{gas}} = 18,2 \text{ MW}$ / $H_{\text{oil}} = 14 \text{ MW}$ the following conditions shall be fulfilled:

- Verification of heat flux and calculation temperature of furnace (e.g. according to 6.1 e).
- The design documentation demonstrates satisfactory integration of the burner with the boiler and the operating instructions contain the full specification details for the boiler/burner combination.

5.5.4 Additional operating conditions

For $H_{\text{gas}} > 18,2 \text{ MW}/H_{\text{oil}} > 14 \text{ MW}$, the boiler manufacturer shall consider additional operating requirements as follows. The risk analysis shall be adapted accordingly:

More stringent operating conditions specified such as improved water quality requirements in addition to the requirements of EN 12953-10:2003, shorter maintenance and/or inspection intervals.

- Temperature monitoring of the furnace shell or equivalent safety / technical measures, if required according to Figure 1.
- More stringent start up conditions, e.g. limitation of the heating rate in the cold start (either automatically within the control system or in the operating instructions) as determined from the boiler/burner integration evaluation.
- Twin furnace boiler: requirements for possible single furnace operation, where the operating requirements necessitate a wide range of heat input.

a) For steam boilers:

- Monitoring of the conductivity of the boiler water shall be in accordance with EN 12953-6:2011.
- Improvement in the circulation during start-up.

b) For hot water boilers:

- Monitoring of the make-up water shall be in accordance with EN 12953-6:2011 as well as the monitoring of the returns for contamination.
- Reliable monitoring of returns for sudden changes in flow rate or temperature.

Where refractory is attached to the furnace shell, the length shall not be longer than one third of the inside diameter of the furnace. The length is defined as starting from the end of the burner. Further refractory or other internals in the furnace for the purpose of storing or retaining heat are not permitted except where they are in accordance with the specification of the burner manufacturer.

5.6 Dimensions of pressure parts

The wall thickness and other dimensions of pressure parts shall be sufficient to withstand the calculation pressure at calculation temperature and shall be determined in accordance with this Part of the European Standard.

5.7 Determination of pressures

5.7.1 Maximum allowable pressure

The maximum allowable pressure PS is the maximum pressure for which the boiler is designed and shall be measured at the highest point of the boiler.

5.7.2 Calculation pressure

The calculation pressure p_c shall be not less than the sum of the maximum allowable pressure and the hydrostatic head. If the latter is less than 3 % of the maximum allowable pressure, the effect of hydrostatic head may be ignored.

NOTE Calculation pressure p_c is also referred to as design pressure p_d . The term calculation pressure p_c is used throughout this European Standard.

5.7.3 Safety valves set pressure

The safety valve(s) set pressure shall not exceed the maximum allowable pressure (see also EN 12953-8:2001).

5.7.4 Hydrostatic test pressure

The standard hydrostatic test pressure shall be not less than that given by Formula (3):

$$p_t = 1,25 p_c \frac{R_{p0,2\ 20}}{R_{p0,2\ t_c}} \quad (3)$$

or

$$p_t = 1,43 p_c \quad (4)$$

whichever is the higher;

where

$R_{p0,2\ 20}$ is the specified value of the yield point at 20 °C;

$R_{p0,2\ t_c}$ see EN 12953-1:2012, Table 1.

The highest ratio of $R_{p0,2\ 20}/R_{p0,2\ t_c}$ shall be taken for the boiler shell and front tube plate (or front plate depending on the configuration) and rear plate (or rear tube plate depending on the configuration) at their calculation temperatures.

In all cases:

- a) The stress in all pressure parts of the boiler and/or the boiler assembly shall not exceed 95 % of their specified yield strength at test temperature;
- b) p_t shall not exceed the calculation pressure for the furnace under test conditions (see 13.1). The value of modulus of elasticity (E) at room temperature shall be used.
- c) For boilers with smoke tubes that are expanded only, the value of $p_t = 1,43 p_c$ shall be used.

5.8 Allowances

5.8.1 Allowance for material supply tolerances and forming processes

The minus tolerance on the ordered nominal wall thickness c_1 is to compensate for minus tolerances resulting from the supply condition of the material.

For subsequent forming processes, the minimum thickness that shall be achieved by the supplier or manufacturer shall be at least the minimum thickness specified in the relevant documents (i.e. drawings, calculation sheets, etc.).

5.8.2 Allowance for metal wastage

For the purpose of design, allowance for metal wastage c_2 shall include corrosion and also erosion and abrasion if these effects are expected to occur.

For components working under normal conditions:

- a) wall thickness ≤ 30 mm a minimum wastage allowance of 0,75 mm shall be taken;
- b) wall thickness > 30 mm and for all flat components, a wastage allowance of 0 mm may be used.

In the case of severe wastage conditions an increased c_2 value shall be selected accordingly.

5.9 Additional material requirements for plates

UT tests according to EN 10160 shall be performed for plates ≥ 30 mm.

5.10 Standardized fittings

If standardized fittings (e.g. elbows, tubes bends, etc.) according to EN 10253-2 are used, additional calculation according to EN 12953-3 is not required.

NOTE Alternative standards may be used and should comply with requirements of the specific EN standards.

5.11 Flanges

If flanges according to EN 1092-1:2007+A1:2013 are used, pressure/temperature ratings (p/t) given in EN 1092-1:2007+A1:2013, Annex G shall be used.

NOTE Alternative standards may be used and should comply with requirements of the specific EN standards.

5.12 Design by analysis

It shall be permissible to design by analysis provided the safety and functional requirements of the components are not impaired. The results of any stress calculations carried out for loadings not explicitly covered by equations in this part of this standard shall be determined by using the criteria given in EN 13445-3:2014.

5.13 Economizer and superheater

For economizer and superheater with water tube design, which are connected to the shell boiler, see Annex D.

6 Calculation temperature and nominal design stress

6.1 Calculation temperature

The calculation temperature t_c shall be the mean metal temperature and shall be determined as specified in a) to e).

- a) For components not subject to heat transfer (e.g. cylindrical shells), the calculation temperature (t_c) shall be not less than the saturation temperature (t_s) corresponding to the maximum allowable pressure or the maximum allowable temperature.
- b) For smoke tubes, the calculation temperature (t_c) shall be determined in accordance with Formulae (5) and (6), whichever is greater:

$$t_c = t_s + 2e_t \quad (5)$$

or

$$t_c = t_s + 25 \quad (6)$$

- c) The calculation temperature for components subject to heat transfer but not swept by flame where the gas entry temperature is not greater than 800 °C, shall be determined in accordance with Formulae (7) and (8), whichever is lower:

$$t_c = t_s + 2e + 15 \quad (7)$$

or

$$t_c = t_s + 50 \quad (8)$$

The calculation temperature (t_c) for components in the flue gas pass where the gas entry temperature is not greater than 400 °C is given by Formula (9):

$$t_c = t_s + 20 \quad (9)$$

- d) The calculation temperature for components subject to heat transfer where the gas entry temperature is greater than 800 °C, shall be determined in accordance with Formula (10) or (11):

$$\text{Heating by radiation: } t_c = t_s + 3e + 30 \quad (10)$$

or

$$\text{Heating by convection: } t_c = t_s + 2e + 15, \text{ but not more than } t_s + 50 \quad (11)$$

or to Annex C

- e) The calculation temperature for furnaces shall be determined by Formula (12):

$$t_c = t_s + 3,5e + 35 \quad (12)$$

Formula (12) can be used to calculate (t_c) provided that:

- 1) $d_i \geq \text{min equivalent } d_i \text{ of furnace (see 5.5.1)}$
- 2) $L \geq \text{min Length of furnace (see Figure 2)}$
- 3) $H_{\text{oil}} \leq 14,0 \text{ MW}$
- 4) $H_{\text{gas}} \leq 18,2 \text{ MW}$

If Formula (12) cannot be used, the calculation temperature (t_c) shall be determined in accordance with the requirements of Annex B.

In all cases, the calculated temperature shall not be less than calculated with Formula (12),

In all cases, the maximum allowable calculation temperature for the furnace shall be 420 °C.

6.2 Nominal design stress

Unless otherwise stated, the nominal design stress f shall be the lower of the two values obtained when Formula (13) is used:

$$f = \min \left\{ \frac{R_{p0,2tc}}{1,5}; \frac{R_m}{2,4} \right\} \quad (13)$$

NOTE The term “nominal design stress”, designated by the symbol f , is the stress to be used in the equations herein for the design of pressure parts. The detailed design rules in this Part will maintain the actual maximum stresses within acceptable limits for the type of loading considered.

7 Cylindrical shells

7.1 Shell thickness

7.1.1 Requirements

After the deduction of allowances, the shell thickness (e_{rs}) is given by Formula (14).

$$e_{rs} = e_s - C_1 - C_2 \quad (14)$$

shall be at least the greatest of those required by the following:

- a) a minimum of 6 mm for shells of outside diameter $\geq 1\,000$ mm except LPB. For outside diameter $< 1\,000$ mm and LPB a minimum of 4 mm shall be required;

b) the requirements of 7.2 by applying 8.2 or 8.3.3 and 8.3.4.

7.1.2 Required wall thickness including allowances

The required wall thickness including allowances is given by Formula (15):

$$e_{sa} = e_{cs} + c_1 + c_2 \quad (15)$$

7.2 Basic calculation subjected to internal pressure

If d_{is} is available, the required wall thickness without allowances (e_{cs}) of a cylindrical shell is given by Formula (16):

$$e_{cs} = \frac{p_c d_{is}}{(2 f_s - p_c) v} \quad (16)$$

If d_{os} is available, the required wall thickness without allowances (e_{cs}) of a cylindrical shell is given by Formula (17):

$$e_{cs} = \frac{p_c d_{os}}{(2 f_s - p_c) v + 2 p_c} \quad (17)$$

7.3 Boiler supports and lifting lugs

The stresses on the boiler shell due to the loads from the supports and the lifting lugs shall be calculated.

NOTE 1 As a guidance, EN 13445-3:2014, Clause 16 may be used for the calculation or by special analysis.

NOTE 2 The supports and the lifting lugs themselves should also be calculated.

8 Openings and branches in cylindrical shells

8.1 General

8.1.1 Introduction

This clause specifies the design rules for openings and branches in cylindrical shells.

Consideration shall be given to:

- all dimensions exclude allowances c_1 and c_2 for wall thickness;
- weld details are only typical.

8.1.2 Requirements for the reinforcement of openings in shells

8.1.2.1 Where applicable, the reinforcement of openings in shells shall be in accordance with the following:

- a) by increasing the wall thickness of the shell calculated according to the Formulae (16) and (17).

The additional wall thickness shall be available at least up to the length l_{rs} according to Figures 4 to 7.

Where the position of the branch or opening is adjacent to any butt weld in the shell, the distance shall be $l_{so} \geq e_{rs}$ (see Figures 5 and 6).

- b) by branches, measured on a length l_{b1} from the outside surface of the shell wall, which have been provided with a wall thickness in excess of that required on account of the internal pressure, without or in connection with an increase in shell wall thickness (see Figures 5 and 6).

The welded joint between the shell and branch shall be a full-penetration weld. Where a full penetration weld cannot be employed, the branch shall not be considered in the reinforcement calculation (see Figure 4).

A wall thickness ratio of e_{rb}/e_{rs} up to and including 2 shall be permitted for $d_{ib} \leq 50$ mm. This shall also apply to branches with $d_{ib} > 50$ mm insofar as the diameter ratio $d_{ib}/d_{is} \leq 0,2$. For branches with $d_{ib} > 50$ mm and a diameter ratio $d_{ib}/d_{is} > 0,2$, e_{rb}/e_{rs} shall not exceed unity. These conditions do not apply to access and inspection openings.

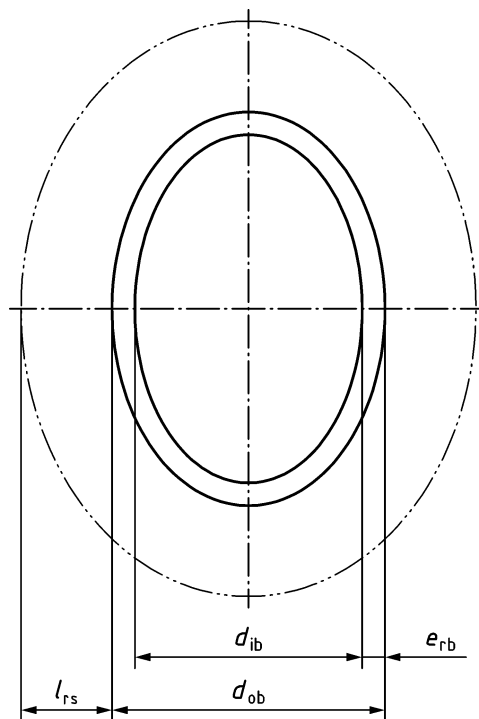
The length l_{rb} in Figure 6 shall be at least equal to the branch thickness e_{rb} .

- c) by reinforcing pads to increase the wall thickness of the shell as in a) (see Figures 7 to 8). The reinforcement of openings by internal reinforcing pads shall not be permitted.
- d) by set-in reinforcing ring which can be used as a flange see Figure 9. The height e_r of the ring used for reinforcement calculation is limited to $\max \{3 \cdot e_{rs}; 3 \cdot l_r\}$. For reinforcement calculation in the following chapters use A_{fr} instead of A_{rb} and f_r instead of f_b .

NOTE Set-on rings (flanges) maybe regarded as reinforcement pad only.

8.1.2.2 Where there are elliptical access and inspection openings the ratio of major to minor axis shall not exceed 1,5.

For elliptical or obround openings in cylindrical shells the diameter of the opening used in the reinforcement calculation shall be the dimension in the direction of the shell axis (see Figure 3).



Key

- d_{ib} inside diameter of branch without allowances
- d_{ob} nominal outside diameter of branch
- e_{rb} actual wall thickness of branch or nozzle without allowances

Figure 3 — Calculation dimensions for elliptical openings

Openings shall be located at an adequate distance from the longitudinal and circumferential welds of the shell.

The distance from the weld edge shall be considered adequate if the outer edge of a branch or welded-on reinforcement for a shell with a thickness:

- a) $e_{rs} \leq 25$ mm is at a distance of $2 e_{rs}$,
- b) $e_{rs} > 25$ mm the distance is at least 50 mm.

Machining of openings through longitudinal and circumferential welds of shells shall be permitted, provided the bore ≥ 100 mm and the branch thickness ≥ 8 mm. The hole shall clear the edge of the main seam weld and be subjected to additional non-destructive examination:

- c) after machining and before welding the branch: surface crack detection of the area concerned,
- d) after welding the branch in addition to the inspection listed in EN 12953-5, surface crack detection and ultrasonic tests (UT).

NOTE It is advised to consider the concerned weld with weld factor $v = 1$.

8.1.3 Effective lengths l_{rs} for calculation of efficiencies and of compensations

For the calculation of efficiencies by way of approximation as described in 8.2 and the calculation of isolated and adjacent branches described in 8.3, effective lengths l_{rs} are required which shall be used for the shell.

$$l_{rs} = \min \left[\sqrt{(d_{is} + e_{rs})e_{rs}}; l_{s1} \right] \quad (18)$$

NOTE If reinforcement rings according to 8.1.2.1 (d) are used, it is allowed to use e_{rs} as the average thickness, obtained considering e_r and e_{rs} by iterative calculation.

for l_{s1} see Figures 4 to 6.

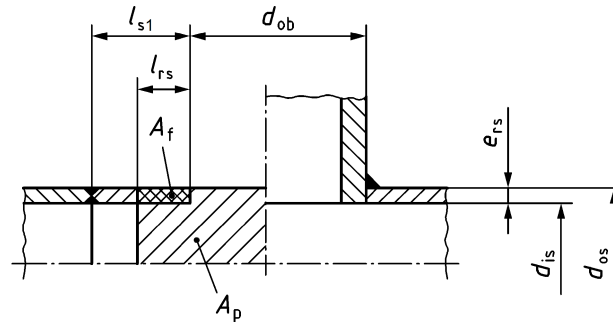
and for the nozzle with $\Psi \geq 45^\circ$

for external projection

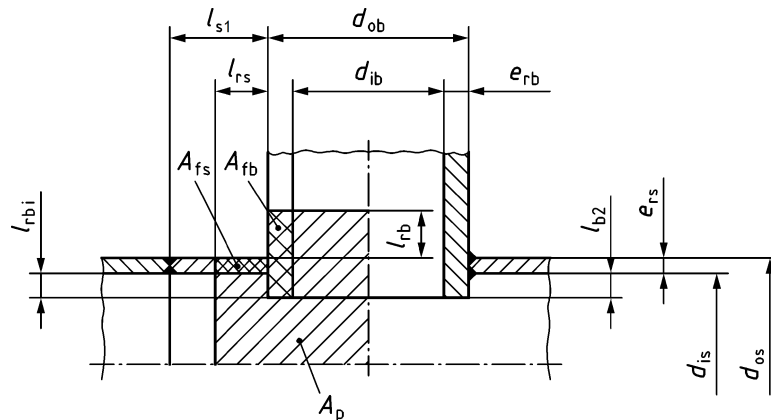
$$l_{rb} = \min \left[\sqrt{(d_{ib} + e_{rb})e_{rb}}; l_{b1} \right] \quad (19)$$

for internal projection

$$l_{rbi} = \min \left[0,5\sqrt{(d_{ib} + e_{rb})e_{rb}}; l_{b2} \right] \quad (20)$$

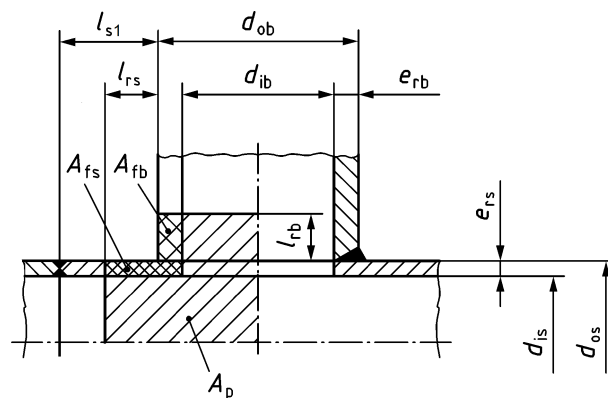
**Key**

- A_f cross-sectional area effective as compensation without consideration of allowances
- A_p pressure-loaded area without consideration of allowances
- e_{rs} actual wall thickness of main body without allowances
- l_{rs} effective length of main body contributing to reinforcement
- d_{os} nominal outside diameter of main body
- d_{is} inside diameter of main body
- d_{ob} nominal diameter of the branch

Figure 4 — Cylindrical shell with fillet welded branch (no additional reinforcement)**Key**

- A_p pressure-loaded area without consideration of allowances
- A_{fs} cross-sectional area of main body effective as compensation
- A_{fb} cross-sectional area of branch effective as compensation
- d_{ib} inside diameter of branch without allowances
- d_{ob} nominal outside diameter of branch
- d_{os} nominal outside diameter of main body
- d_{is} inside diameter of main body
- e_{rb} actual wall thickness of branch or nozzle without allowances
- e_{rs} actual wall thickness of main body without allowances
- l_{b2} measured length of internal projection of branch
- l_{rb} effective length of branch contributing to reinforcement
- l_{rbi} effective length of inward projection of set-through branch contributing to reinforcement
- l_{rs} effective length of main body contributing to reinforcement

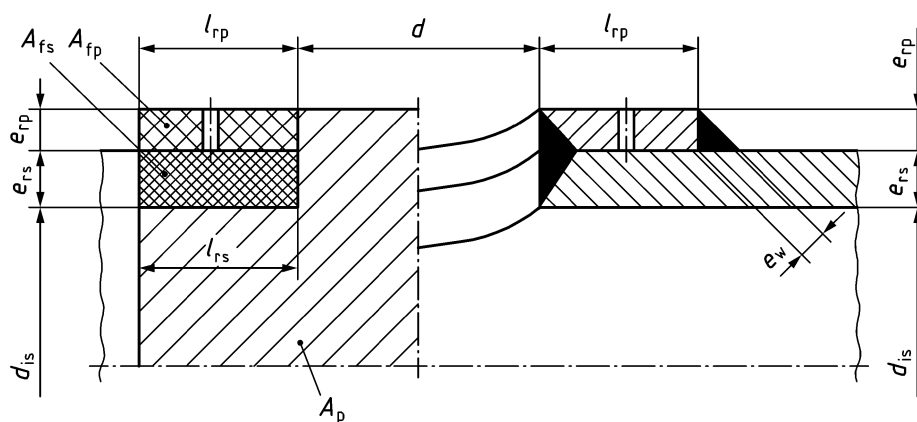
Figure 5 — Cylindrical shell with full penetration welded branch (set-through)



Key

- A_p pressure-loaded area without consideration of allowances
- A_{fs} cross-sectional area of main body effective as compensation
- A_{fb} cross-sectional area of branch effective as compensation
- d_{ib} inside diameter of branch without allowances
- d_{ob} nominal outside diameter of branch
- d_{os} nominal outside diameter of main body
- d_{is} inside diameter of main body
- e_{rb} actual wall thickness of branch or nozzle without allowances
- e_{rs} actual wall thickness of main body without allowances
- l_{rb} effective length of branch contributing to reinforcement
- l_{rs} effective length of main body contributing to reinforcement

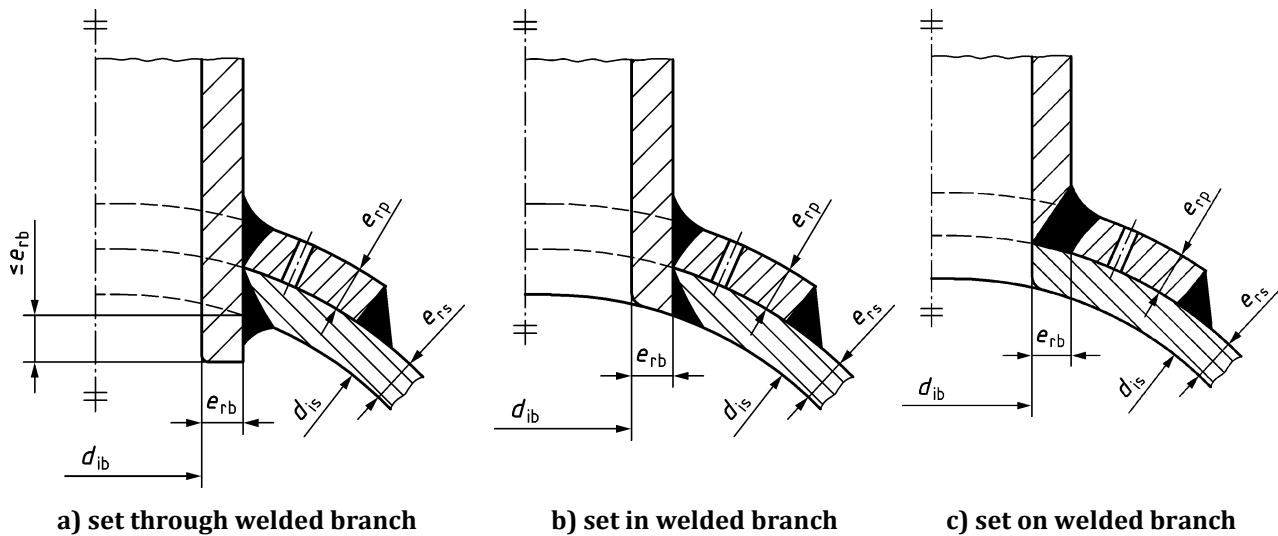
Figure 6 — Cylindrical shell with welded-on branch



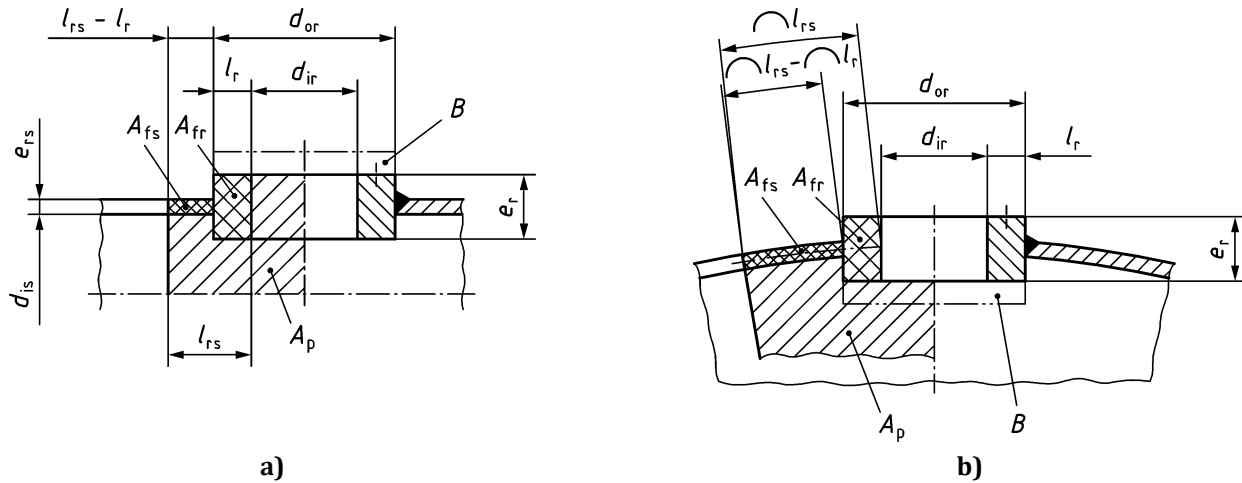
Key

- A_p pressure-loaded area without consideration of allowances
- A_{fs} cross-sectional area of main body effective as compensation
- A_{fp} cross-sectional area of reinforcing pad effective as compensation
- d_{is} inside diameter of main body
- e_{rp} actual wall thickness of reinforcing pad without allowances
- e_{rs} actual wall thickness of main body without allowances
- e_w thickness of the weld ($e_w \geq 0,7 e_{rp}$)
- l_{rb} effective length of branch contributing to reinforcement
- l_{rs} effective length of main body contributing to reinforcement
- l_{rp} effective width of reinforcing ring
- d diameter of tube hole

Figure 7 — Opening with reinforcing pad

**Key**

- d_{ib} inside diameter of branch without allowances
 d_{is} inside diameter of main body
 e_{rb} actual wall thickness of branch or nozzle without allowances
 e_{rp} actual wall thickness of reinforcing pad without allowances
 e_{rs} actual wall thickness of main body without allowances

Figure 8 — Opening with reinforcing pad and full penetration branch**Key**

- A_p pressure-loaded area without consideration of allowances
 A_{fs} cross-sectional area of main body effective as compensation
 A_{fr} cross-sectional area of the reinforcing ring
 d_{or} outside diameter of the ring
 d_{ir} inside diameter of the ring
 d_{is} inside diameter of main body
 e_r height of the ring
 e_{rs} actual wall thickness of main body without allowances
 l_r width of the ring
 l_{rs} effective length of main body contributing to reinforcement
 B location of an optional blind flange

Figure 9 — Opening with reinforcing ring (flange)

8.1.4 Condition of isolated openings

Adjacent openings shall be treated as isolated openings if, for the centre distance P_ϕ (as shown in Figure 14), the condition shown in Formula (21) is met.

$$P_\phi \geq \left(\frac{d_{ib1}}{2} + e_{rb1} \right) + \left(\frac{d_{ib2}}{2} + e_{rb2} \right) + 2 \sqrt{(d_{is} + e_{rs}) e_{rs}} \quad (21)$$

For openings without a branch, $e_{rb} = 0$.

8.1.5 Requirements for design of branches

8.1.5.1 Shell with lower design stress than the branches

If the shell, the branch and the additional reinforcement consists of materials with different design stresses and the material of the shell has the lowest design stress value f_s , this value shall be used for all materials to calculate the reinforcement of the opening such that f_p and f_b are both equal to f_s .

8.1.5.2 Branches or reinforcing pads with lower design stress than the shell

If the material used for the branch or the reinforcing pad has a lower design stress f_b or f_p respectively than the shell design stress f_s , this design stress f_b or f_p shall be taken into account when using the equations provided for this case.

8.1.5.3 Special case

The nozzle inside diameter d_{ib} shall be used in the calculation even if the hole diameter d in the shell is less than d_{ib} .

8.1.6 Requirements for design of reinforcing pads

8.1.6.1 General

Reinforcing pads shall be designed in accordance with 8.1.2.

If reinforcing pads are used (see Figures 7 and 8) they shall have close contact with the shell and shall be provided with tell-tale (vent) holes to avoid the trapping of gases.

8.1.6.2 Pressure considerations

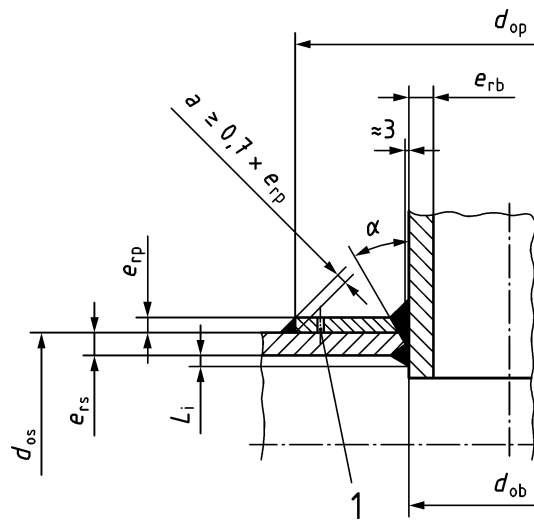
If reinforcing pads are used for the reinforcement of openings, the following conditions shall be observed.

If reinforcing pads are used for the reinforcement of openings, the branch weld to shell shall meet the requirements of EN 12953-4 and:

- a) the ratio d_{ib}/d_{is} of the diameter of the branch to the diameter of the cylinder shell shall not exceed 1/4.

The size a of the pad weld to the shell shall be $\geq 0,7 e_{rp}$ (see Figure 10).

- b) for calculation purposes the thickness of the reinforcing pad shall not exceed the thickness of the shell.

**Key**

- d_{ob} nominal outside diameter of branch
- d_{op} outer diameter of compensating plate
- e_{rb} actual wall thickness of the branch without allowances
- e_{rs} actual wall thickness of the shell without allowances
- e_{rp} actual wall thickness of reinforcing pad without allowances
- L_i length of leg of fillet weld
- 1 tell-tale (vent) hole
- α is 30° to 45°

Figure 10 — Welding of reinforcing pads by set-through and full penetration welded branch

8.1.7 General requirements for calculation of cross-sectional and pressure-loaded areas

The shell inside diameter shall be calculated using Formula (22).

$$d_{is} = d_{os} - 2 * (e_s - c_1 - c_2) \quad (22)$$

The branch inside diameter shall be calculated using Formula (23).

$$d_{ib} = d_{ob} - 2 * (e_b - c_1 - c_2) \quad (23)$$

No corrosion allowance shall be made for pads.

For cross-sectional areas, thicknesses shall be calculated with nominal wall thickness reduced by allowances for minus tolerances (c_1) and metal wastage (c_2).

In situations where the component is contacted by the medium from both sides, allowances for metal wastages shall only be considered once.

8.2 Efficiency factor, alternative calculation method, maximum diameter of an un-reinforced opening

8.2.1 General

As an alternative to the equations in 8.3.3 and 8.3.4, the equations in 8.2.3 and 8.2.4 may be used. However, the Formula (26) may produce conservative result as any reinforcement from the branch is not taken into account.

8.2.2 Allowable efficiency and maximum diameter of an unreinforced opening

Rearranging Formula (16) the allowable efficiency v_a shall be calculated for the available wall thickness e_{rs} of a shell using Formula (24):

$$v_a = \frac{p_c d_{is}}{(2 f_s - p_c) e_{rs}} \quad (24)$$

For this efficiency coefficient the greatest outside diameter d_{ob} of an isolated branch shall be obtained when its wall thickness can only withstand the internal pressure

$$d_{ob \max} = 2 \left(\frac{l_{rs}}{v_a} - l_{rs} \right) \quad (25)$$

In this case the available average stress f_a shall be equal to the allowable stress f_s of the shell.

8.2.3 Isolated openings

The equations in this clause shall apply to single openings, or if there is more than one opening, only if Formula (21) is satisfied. In the case of more than one opening where Formula (21) is not satisfied, reference shall be made to 8.3.3.

However, isolated unreinforced openings with diameter d in cylindrical shells shall be permitted if they meet the requirements of Formulae (26) and (27):

$$d \leq 0,14 l_{rs} \quad (26)$$

and

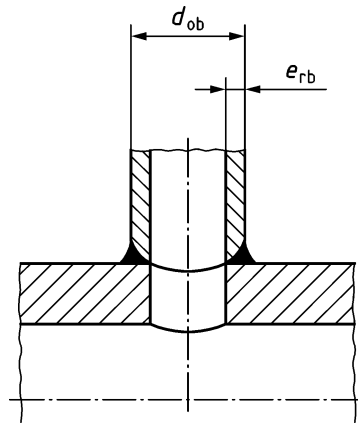
$$e_{rs} \leq 0,1 d_{os} \quad (27)$$

where l_{rs} shall be calculated in accordance with 8.1.3.

This shall also be valid for counter borings and for partial penetration holes even if the Formulae (29) or (32) or the more exact calculations in accordance with 8.3.3 recommend a smaller diameter d as given in Formula (26).

Where a tube with an outside diameter d_{ob} is attached to an opening, as shown in Figure 11, and the tube is capable of withstanding the internal calculation pressure on account of its wall thickness e_{rb} , the efficiency factor v_b of this opening in the shell shall be calculated by

$$v_b = \frac{2 l_{rs}}{(2 l_{rs} + d_{ob})} \quad (28)$$

**Key**

d_{ob} nominal outside diameter of branch

e_{rb} actual wall thickness of branch or nozzle without allowances

Figure 11 — Tube attached to shell

If the diameter d_{is} and the wall thickness e_{rs} of the shell have been determined, an isolated hole for a tube with a maximum outside diameter

$$d_{ob} \leq 2l_{rs} \left[\frac{2e_{rs}}{d_{is}} \left(\frac{f_s}{p_c} - \frac{1}{2} \right) - 1 \right] \quad (29)$$

shall be permitted.

8.2.4 Adjacent openings

Where the condition for the centre distance P_Φ of adjacent openings given in 8.1.3 is not met, and tubes with an outside diameter d_{ob} are connected to the opening, with the tubes only able to withstand the internal pressure on account of their wall thickness e_{rb} , the efficiency factor of adjacent openings shall be derived using Formulae (30) and (31):

$$v_m = \frac{2(P_\Phi - d_{ob})}{(1 + \cos^2 \Phi) P_\Phi} \leq 1 \quad (30)$$

i.e. for longitudinal pitch P_Φ with $\Phi = 0$:

$$v_m = \frac{P_\Phi - d_{ob}}{P_\Phi} \quad (31)$$

Where the outside diameters of adjacent openings differ from each other, the requirements of Formula (32) apply:

$$d_{ob} = \frac{d_{ob1} + d_{ob2}}{2} \quad (32)$$

Instead of the calculation by approximation used in this clause, 8.3.4 may be used.

8.3 Design of openings and branches in shells (efficiency and reinforcement)

8.3.1 Symbols and abbreviations

In addition to the symbols given in EN 12953-1:2012, those shown in Figures 12 to 15 shall be used.

8.3.2 Requirements for application

8.3.2.1 Openings

The rules specified in 8.3.3 to 8.3.4 shall apply to circular, elliptical and obround openings and nozzles (including oblique nozzles) arranged singly or in groups, in shells, provided that the following conditions apply:

- a) Openings and nozzles non radial to the shell (Figure 13)

The ratio of the major to minor axes of the opening shall not exceed 2;

- b) Oblique nozzles (Figure 12)

The nozzle is of circular cross section and the angle between the axis of the nozzle and a line normal to the shell surface shall not exceed 45°;

- c) All nozzles

No significant external forces and moments shall be applied to the nozzle. If this is not the case, EN 13445-3:2014 shall be used to calculate the resulting stresses.

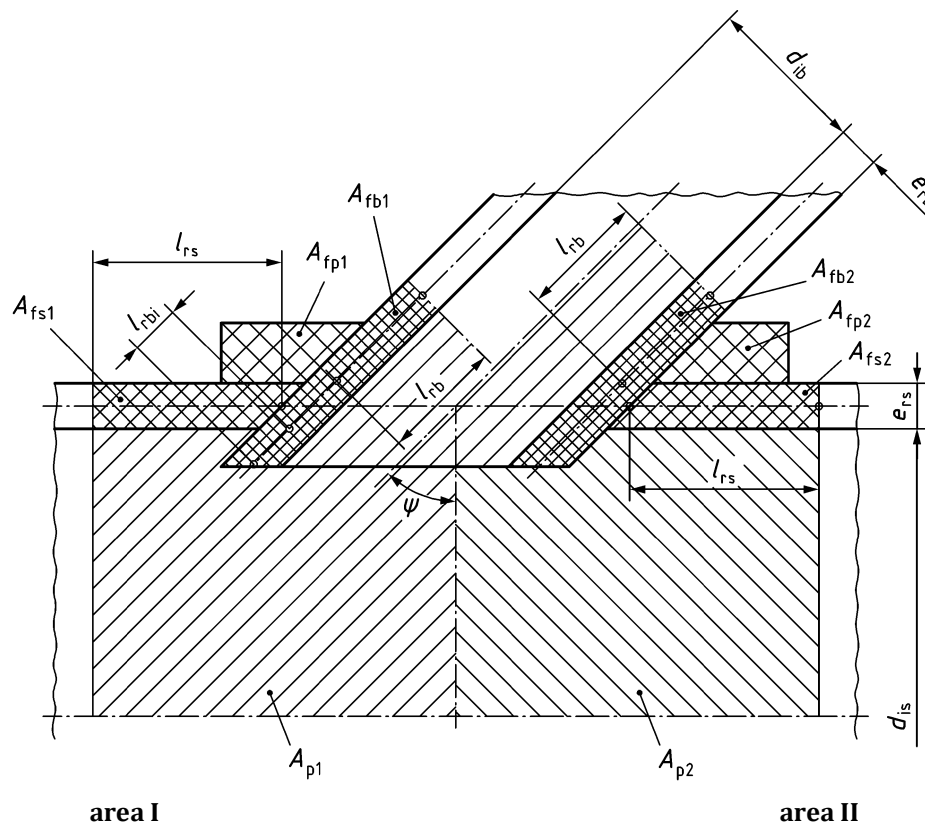
The nozzle inside diameter d_{ib} shall be used in the calculation even if the hole diameter d in the shell is less than d_{ib} .

Nozzle connections to the shell without full penetration or set-through branches with fillet weld, shall be considered as openings without reinforcement by the nozzle.

The pressurized area in the tube hole shall be considered. For the case of set-through tubes with an internal fillet weld the pressurized area shall be treated the same as for a full penetration weld.

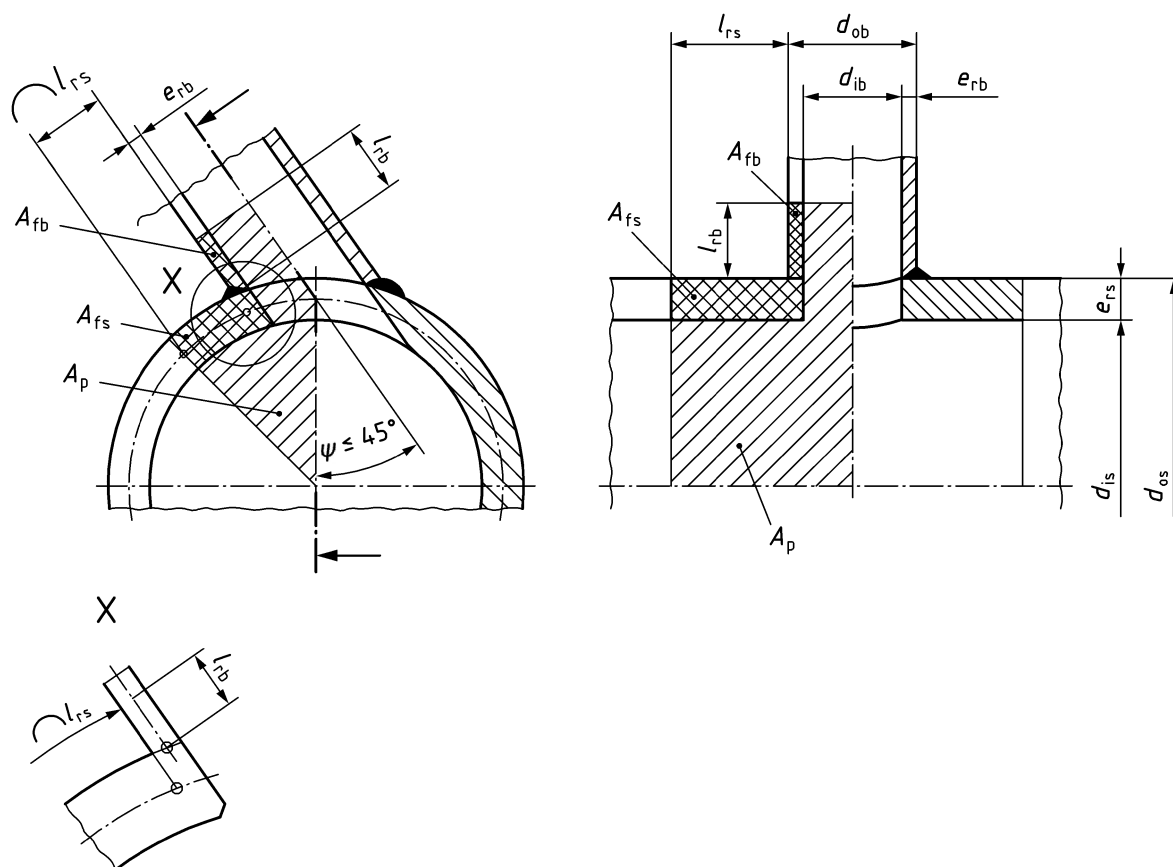
8.3.2.2 Minimum thickness of nozzles and branch connections

The thickness of nozzles and branches shall take into consideration 8.1.2.1b), but the thickness shall be not less than that given in Clause 12.

**Key**

- A_{fs} cross-sectional area of main body effective as compensation
- A_p pressure-loaded area without consideration of allowances
- A_{fp} cross-sectional area of reinforcing pad effective as compensation
- A_{fb} cross-sectional area of branch effective as compensation
- d_{ib} inside diameter of branch without allowances
- d_{is} inside diameter of main body
- e_{rb} actual wall thickness of branch or nozzle without allowances
- e_{rs} actual wall thickness of main body without allowances
- l_{rb} effective length of branch contributing to reinforcement
- l_{rs} effective length of main body contributing to reinforcement
- $\psi \leq 45^\circ$

Figure 12 — Load diagram for cylindrical shell with oblique branch and reinforcing pad

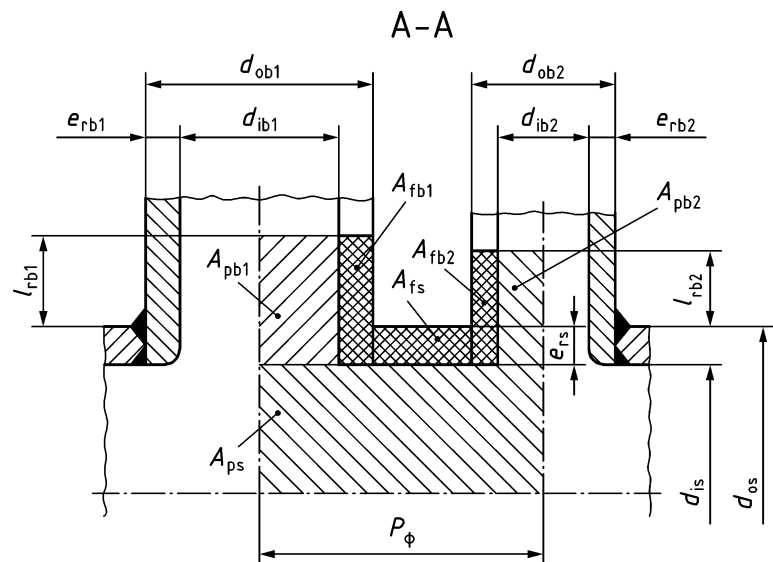


Key

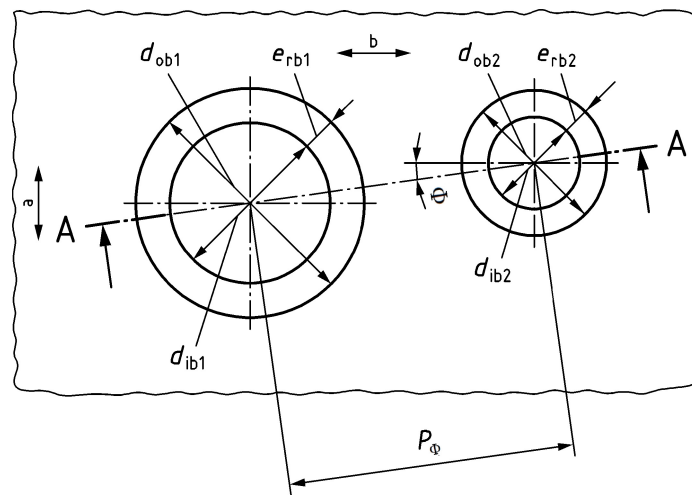
- A_{fs} cross-sectional area of main body effective as compensation
- A_p pressure-loaded area without consideration of allowances
- A_{fb} cross-sectional area of branch effective as compensation
- d_{ib} inside diameter of branch without allowances
- d_{is} inside diameter of main body
- d_{ob} nominal outside diameter of branch
- d_{os} nominal outside diameter of main body
- e_{rb} actual wall thickness of branch or nozzle without allowances
- e_{rs} actual wall thickness of main body without allowances
- l_{rb} effective length of branch contributing to reinforcement
- l_{rs} effective length of main body contributing to reinforcement
- $\psi \leq 45^\circ$

Figure 13 — Load diagram for cylindrical shell with non-radial branch

a) section view A — A



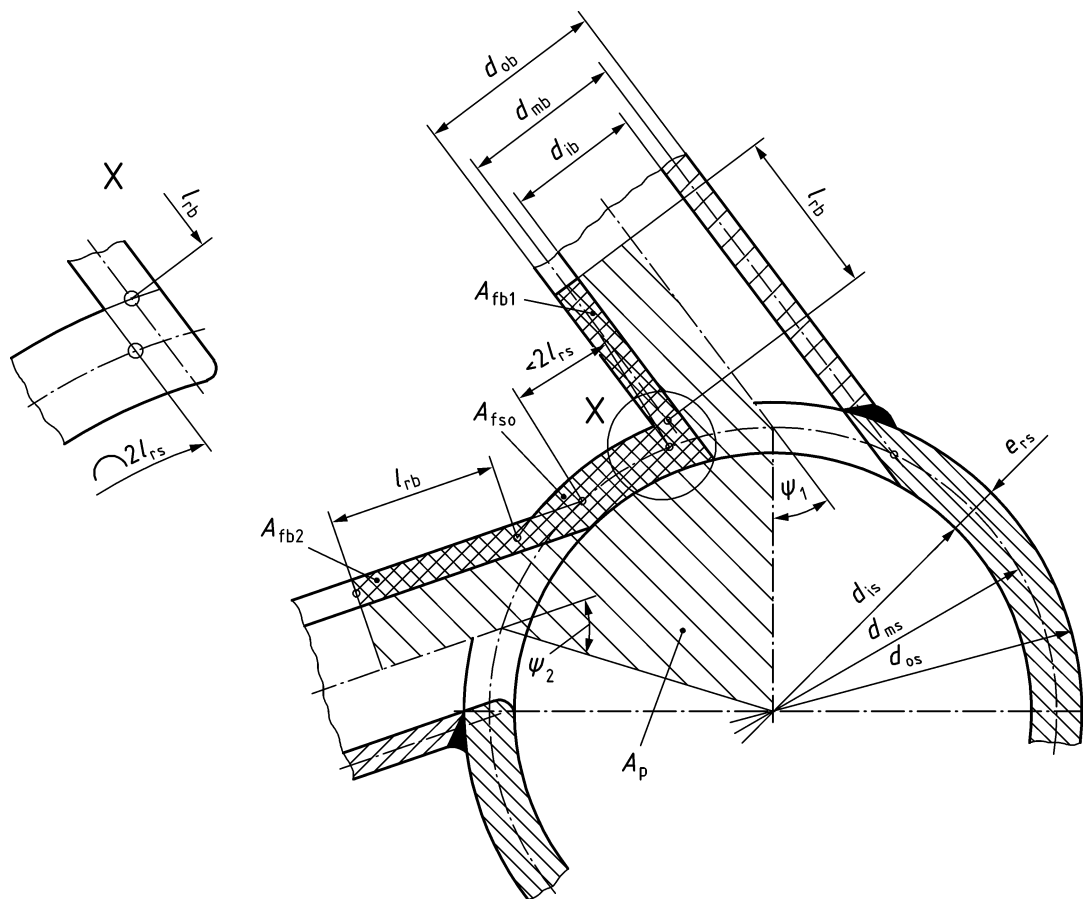
b) plan view



Key

- A_{fs} cross-sectional area of main body effective as compensation
 - A_{fb} cross-sectional area of branch effective as compensation
 - A_{pb} pressure-loaded area relative to branch
 - A_{ps} pressure-loaded area relative to main body
 - d_{ib} inside diameter of branch without allowances
 - d_{is} inside diameter of main body
 - d_{ob} nominal outside diameter of branch
 - d_{os} nominal outside diameter of main body
 - e_{rb} actual wall thickness of branch or nozzle without allowances
 - e_{rs} actual wall thickness of main body without allowances
 - l_{rb} effective length of branch contributing to reinforcement
 - P_{Φ} centre-to-centre distance of adjacent openings, staggered by the angle Φ referring to centre of wall
 - a circumferential direction
 - b longitudinal direction
- NOTE For a) section view A — A, P_{Φ} drawn for $\Phi = 0$.

Figure 14 — Load diagram for cylindrical shell with adjacent branches arranged with an angle Φ to the axis of the shell



Key

- A_{fs} cross-sectional area of main body effective as compensation
- A_{fb} cross-sectional area of branch effective as compensation
- A_p pressure-loaded area without consideration of allowances
- d_{os} nominal outside diameter of main body
- d_{ms} mean diameter of main body
- d_{is} inside diameter of main body
- d_{ob} nominal outside diameter of branch
- d_{mb} mean diameter of branch
- d_{ib} inside diameter of branch without allowances
- e_{rs} actual wall thickness of main body without allowances
- l_{rb} effective length of branch contributing to reinforcement
- l_{rs} effective length of main body contributing to reinforcement

Figure 15 — Load diagram for cylindrical shell with non-radial adjacent branches, arranged on the circumference

8.3.3 Design of isolated openings and branch connections

8.3.3.1 General

The shell thickness e_{rs} and the thickness of a branch connection e_{rb} shall be not less than that calculated for $\nu = 1$ in accordance with 7.2.

8.3.3.2 Isolated opening with a radial branch

8.3.3.2.1 For isolated openings fitted with a radial branch without additional reinforcement 8.3.3.4 (with $\psi_1 = 0$) shall be additionally taken into account.

8.3.3.2.2 If the design stress of the branch is equal to or greater than that for the shell the condition given by Formula (33) shall be met:

$$f_a = p_c \left(\frac{A_p}{A_{fs} + A_{fb}} + \frac{1}{2} \right) \leq f_s \quad (33)$$

The efficiency shall be:

$$v_b = \frac{d_{is} (A_{fs} + A_{fb})}{2 e_{rs} A_p} \leq 1 \quad (34)$$

NOTE The approximate calculation in accordance with 8.2 can be used instead of this calculation, in which case the reinforcement effect of the nozzles should not be considered.

8.3.3.2.3 If the design stress of the branch is less than that of the shell, the condition given by Formula (35) shall be met:

$$f_a = \frac{p_c (2 A_p + A_{fs} + A_{fb})}{2 \left(A_{fs} + \frac{f_b}{f_s} A_{fb} \right)} \leq f_s \quad (35)$$

In this case the efficiency shall be:

$$v_b = \frac{d_{is} \left(A_{fs} + \frac{f_b}{f_s} A_{fb} \right)}{e_{rs} \left(2 A_p + A_{fb} - \frac{f_b}{f_s} A_{fb} \right)} \leq 1 \quad (36)$$

NOTE The approximate calculation in accordance with 8.2 can be used instead of this calculation, in which case the reinforcement effect of the nozzles should not be considered.

8.3.3.3 Isolated opening with an oblique branch and additional reinforcing pad

8.3.3.3.1 For isolated openings fitted with an oblique branch and additional reinforcing pad in accordance with Figure 12, the requirements for design of reinforcing pads in 8.1.5 shall be additionally taken into consideration.

8.3.3.3.2 If the design stress of the branch is equal to or greater than that for the shell, the strength condition for area I shall be:

$$f_{aI} = p_c \left(\frac{A_{pI}}{A_{fsI} + A_{fbI} + 0,7 A_{fpI}} + \frac{1}{2} \right) \leq f_s \quad (37)$$

and for area II

$$f_{aII} = p_c \left(\frac{A_{pII}}{A_{fsII} + A_{fbII} + 0,7 A_{fpII}} + \frac{1}{2} \right) \leq f_s \quad (38)$$