BS EN 12953-3:2016

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. It supersedes BS EN 12953-3:2002 which is withdrawn.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 secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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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of an identical text or by endorsement, at the latest by November 2016, and conflicting national standards shall be withdrawn at the latest by November 2016.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.

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

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

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 ΔP = 20 % of PS is ≤ 100 000 or, alternatively, in the range of ΔP = 40 % of PS is ≤ 10 000;

c) For material with specified yield strength at room temperature > 295 MPa the number of partial pressure cycles in the range of ΔP = 10 % of PS is ≤ 100 000 or, alternatively, in the range of ΔP = 20 % of PS is ≤ 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):

$$p_{\mathrm{t}} = 2{,}2\, p_{\mathrm{c}} \frac{R_{\mathrm{p0,2\,20}}}{R_{\mathrm{p0,2\,tc}}} \cdot \frac{e_{cs} + c_2}{e_{cs}} \tag{1}$$

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

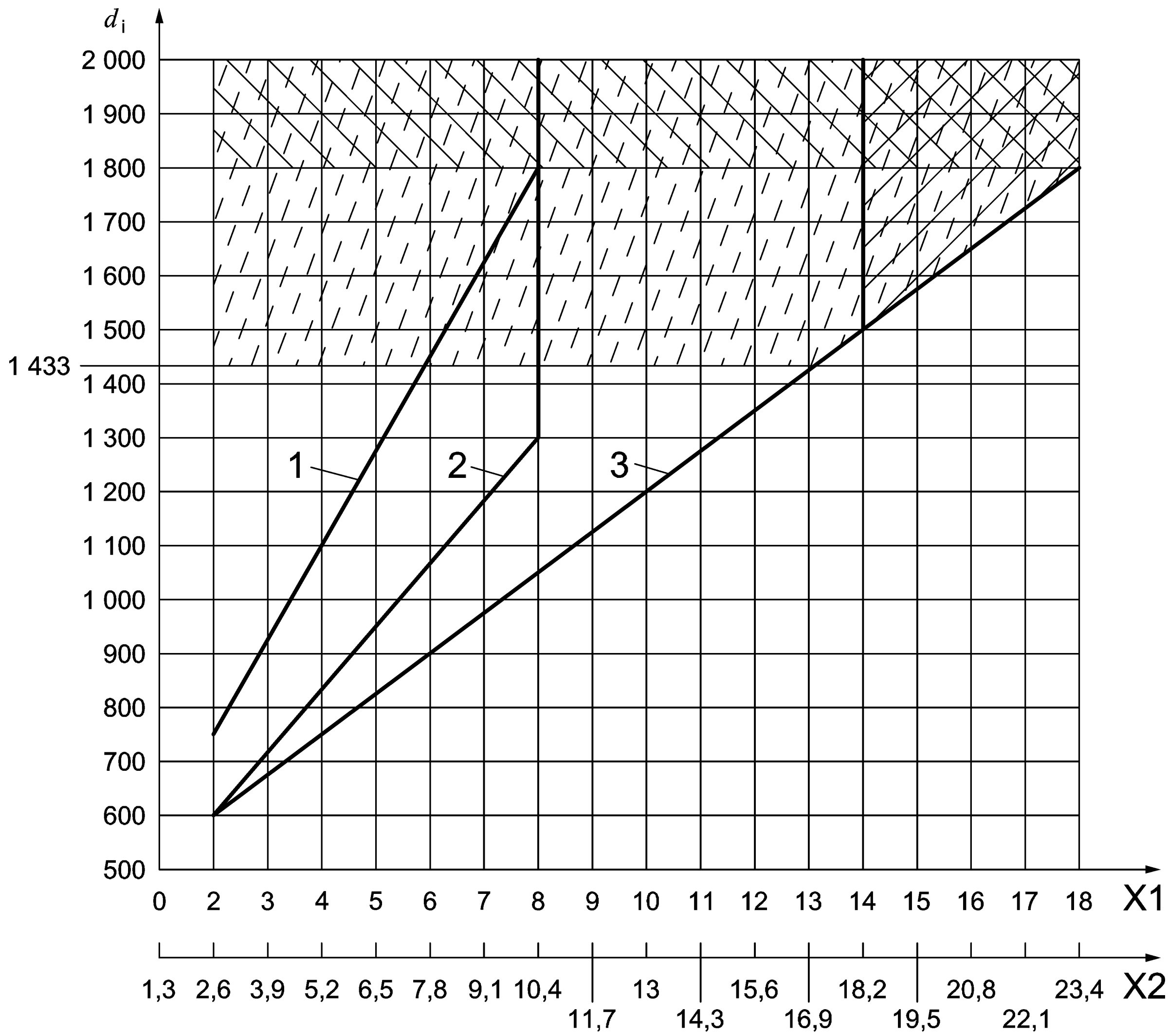
b) No 2 Material grade P265GH: Oil firing: d_{i} = 365 + 117 * H Gas firing: d_{i} = 365 + 90,4 * H

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

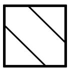
2 P265GH

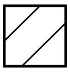
3 P295GH / P355GH

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]

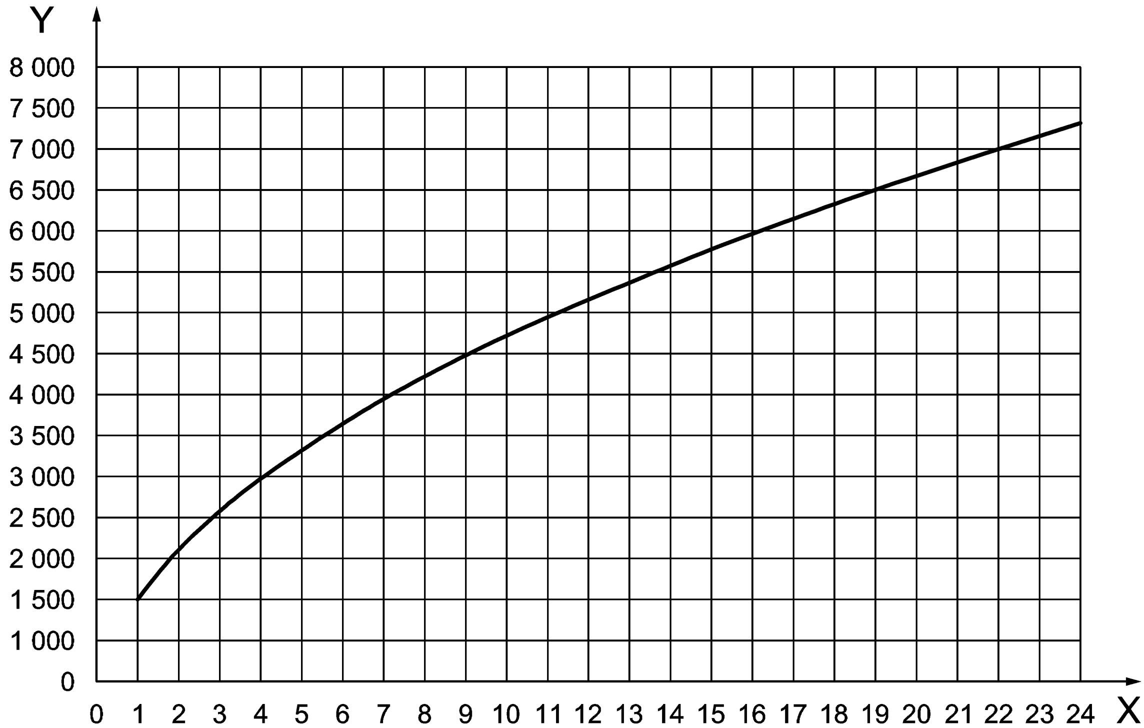
X2 heat input H_{gas} [MW]


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):

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

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_{gas} = 18,2 MW / H_{oil} = 14 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_{gas}> 18,2 MW/H_{oil} >14 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):

$$p_t = 1{,}25\, p_c \frac{R_{p0,2\,20}}{R_{p0,2\,tc}} \tag{3}$$

or

$$p_t = 1{,}43\, p_c \tag{4}$$

whichever is the higher;

where

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

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

The highest ratio of $R_{p0,2\ 20}/R_{p0,2\ tc}$ 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):

Heating by radiation: $t_c = t_s + 3e + 30$ (10)

or

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

or to Annex C

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

$$t_c = t_s + 3{,}5e + 35 \qquad (12)$$

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

1) $d_i \geq$ min equivalent d_i of furnace (see 5.5.1)

2) $L \geq$ min Length of furnace (see Figure 2)

3) $H_{oil} \leq 14{,}0$ MW

4) $H_{gas} \leq 18{,}2$ 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:

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

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).

$$e_{rs} = e_s - c_1 - c_2 \qquad (14)$$

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

a) a minimum of 6 mm for shells of outside diameter ≥ 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):

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

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):

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

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

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

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}.

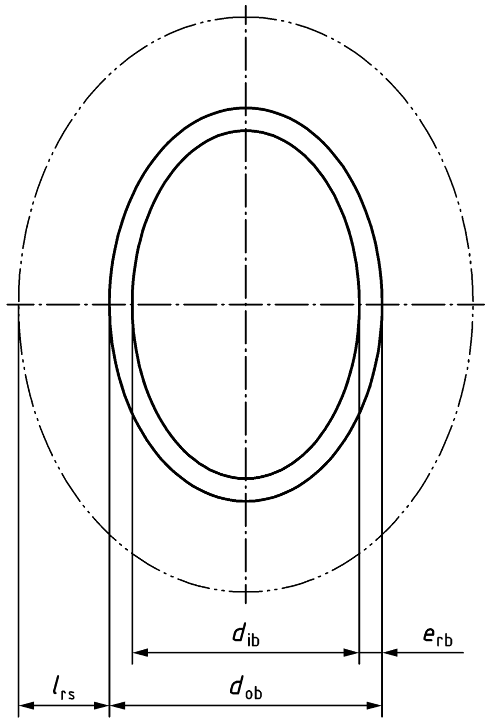
c) by reinforcing pads to increase the wall thickness of the shell as in a) (see Figures 7 to 8). The reinforcement of openings by internal reinforcing pads shall not be permitted.

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_{fb} 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.

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

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.

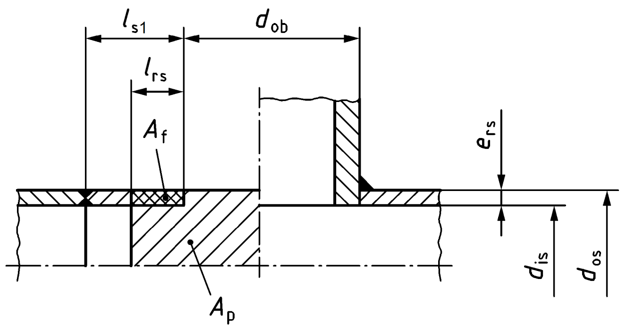
and for the nozzle with $\Psi \geq 45°$

for external projection

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

for internal projection

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



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

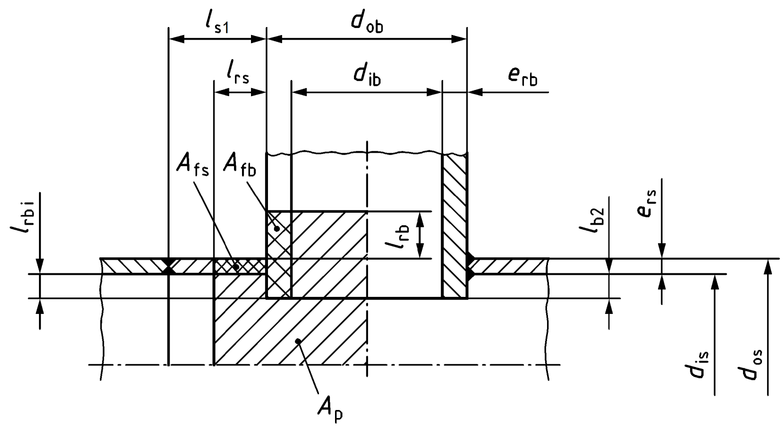
l_{rs} effective length of main body contributing to reinforcement

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

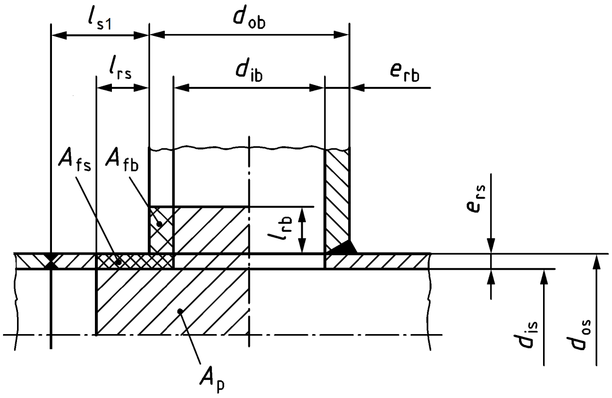
l_{b2} measured length of internal projection of branch

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

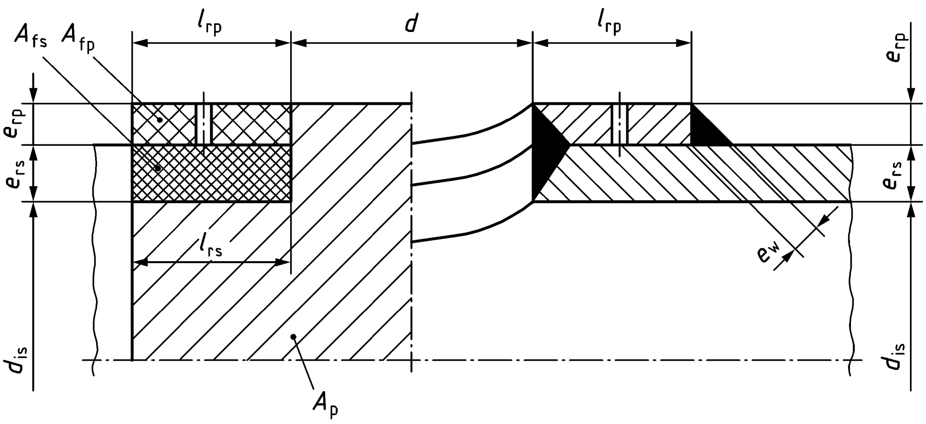
e_{rb} actual wall thickness of branch or nozzle without allowances

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 ($e_w \geq 0,7\ e_{rp}$)

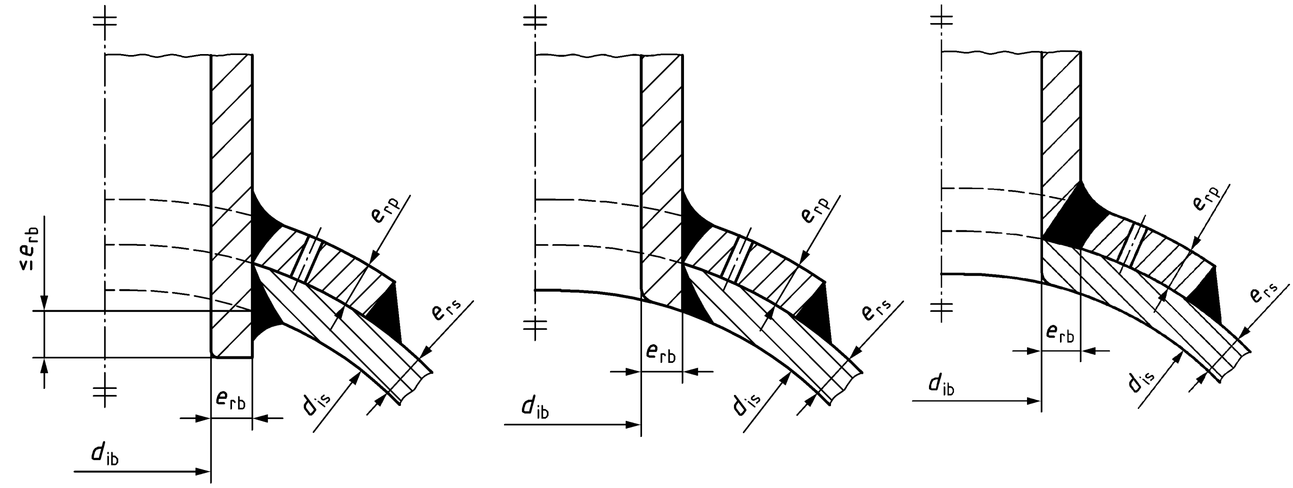
l_{rb} effective length of branch contributing to reinforcement

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



a) set through welded branch **b) set in welded branch** **c) set on welded branch**

Key

d_{ib} inside diameter of branch without allowances

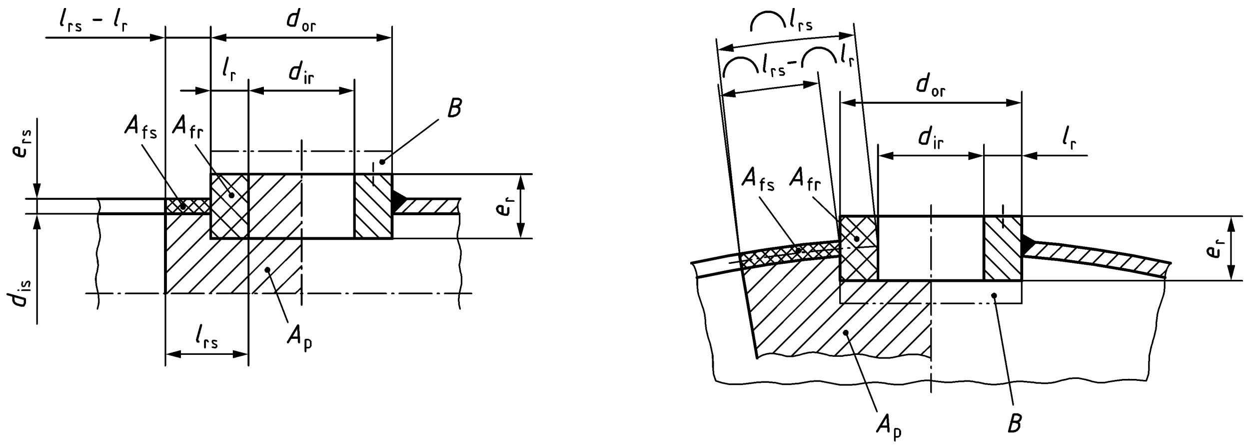
d_{is} inside diameter of main body

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



a) **b)**

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.

$$P\Phi \geq \left(\frac{d_{ib1}}{2} + e_{rb1}\right) + \left(\frac{d_{ib2}}{2} + e_{rb2}\right) + 2\sqrt{(d_{is} + e_{rs})\, e_{rs}} \qquad (21)$$

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.

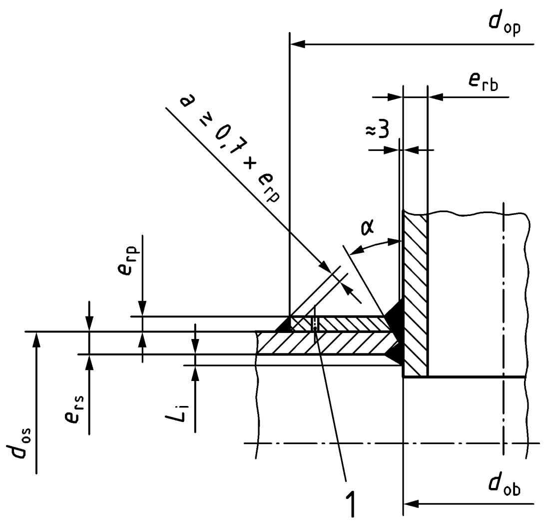
If reinforcing pads are used for the reinforcement of openings, the branch weld to shell shall meet the requirements of EN 12953-4 and:

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 ≥ 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.

Dimensions in millimetres



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):

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

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

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

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):

$$d \leq 0{,}14\, l_{rs} \tag{26}$$

and

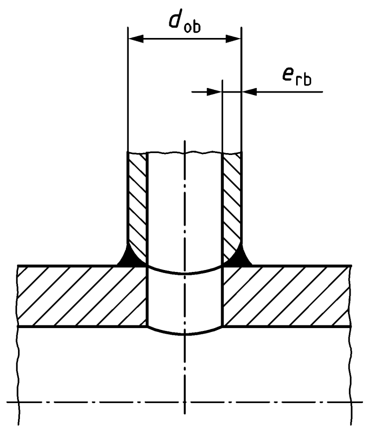
$$e_{rs} \leq 0{,}1\, d_{os} \tag{27}$$

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

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



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):

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

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.

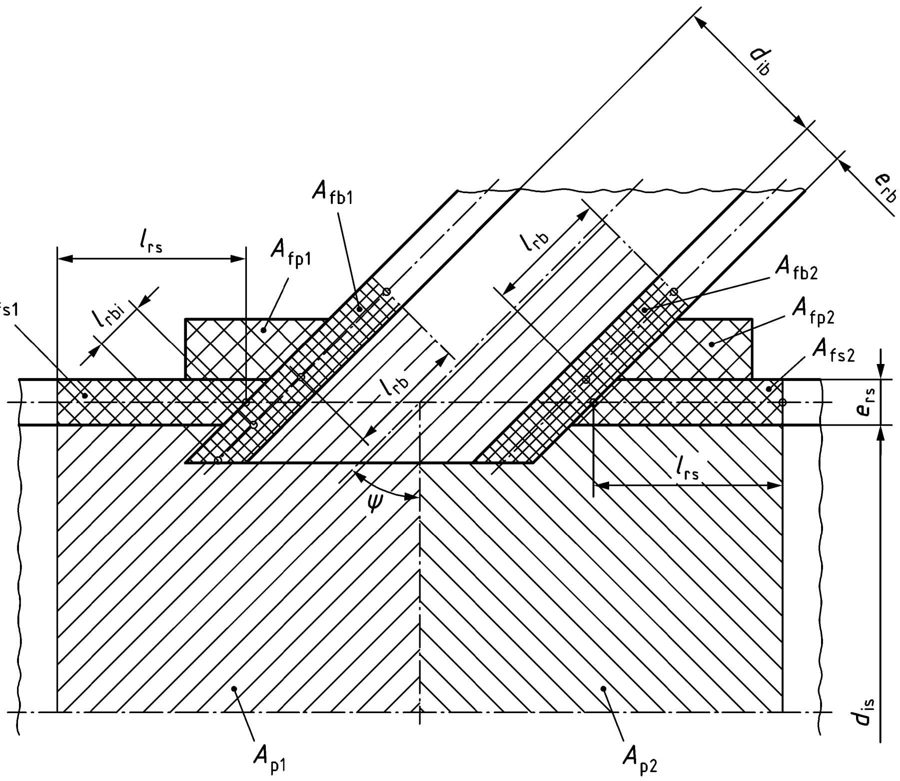
The nozzle inside diameter d_{ib} shall be used in the calculation even if the hole diameter d in the shell is less than d_{ib}.

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

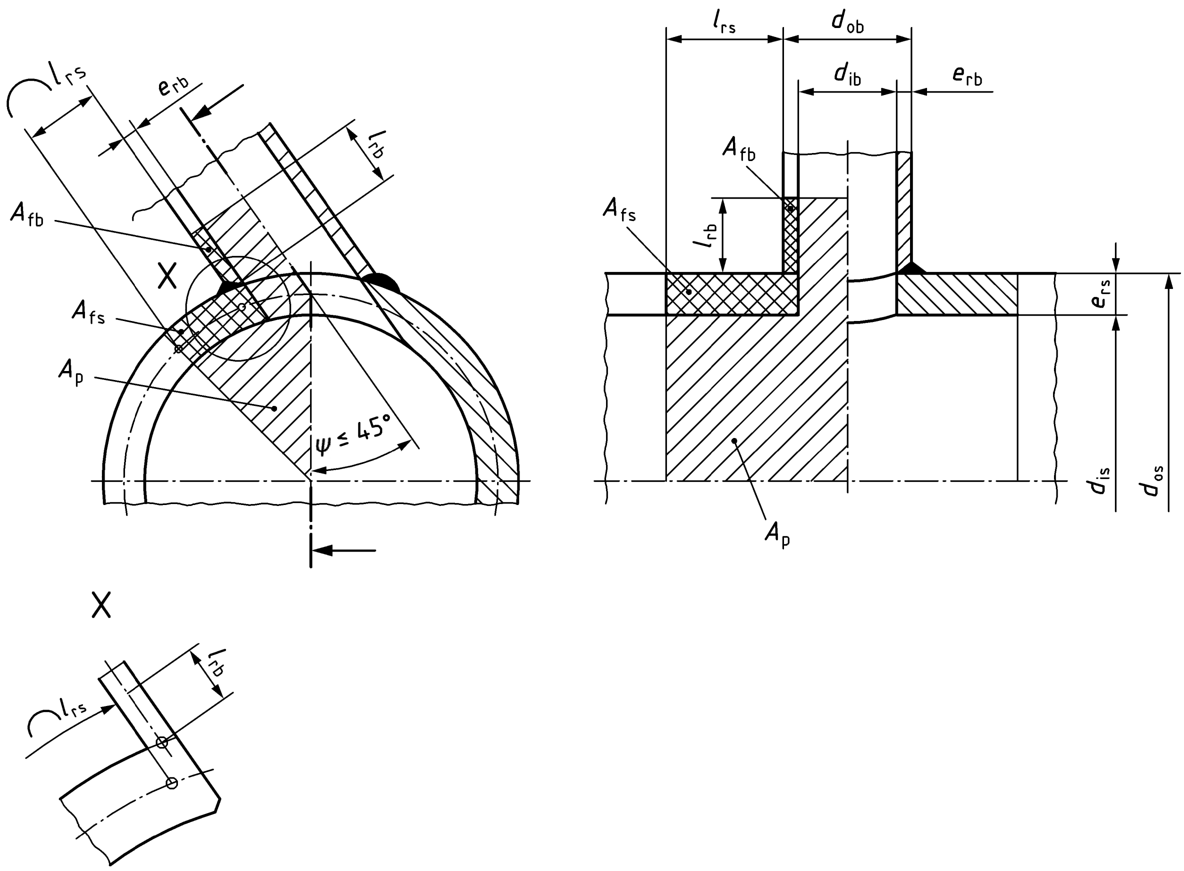
e_{rs} actual wall thickness of main body without allowances

l_{rb} effective length of branch contributing to reinforcement

l_{rs} effective length of main body contributing to reinforcement

$\Psi \leq 45°$

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

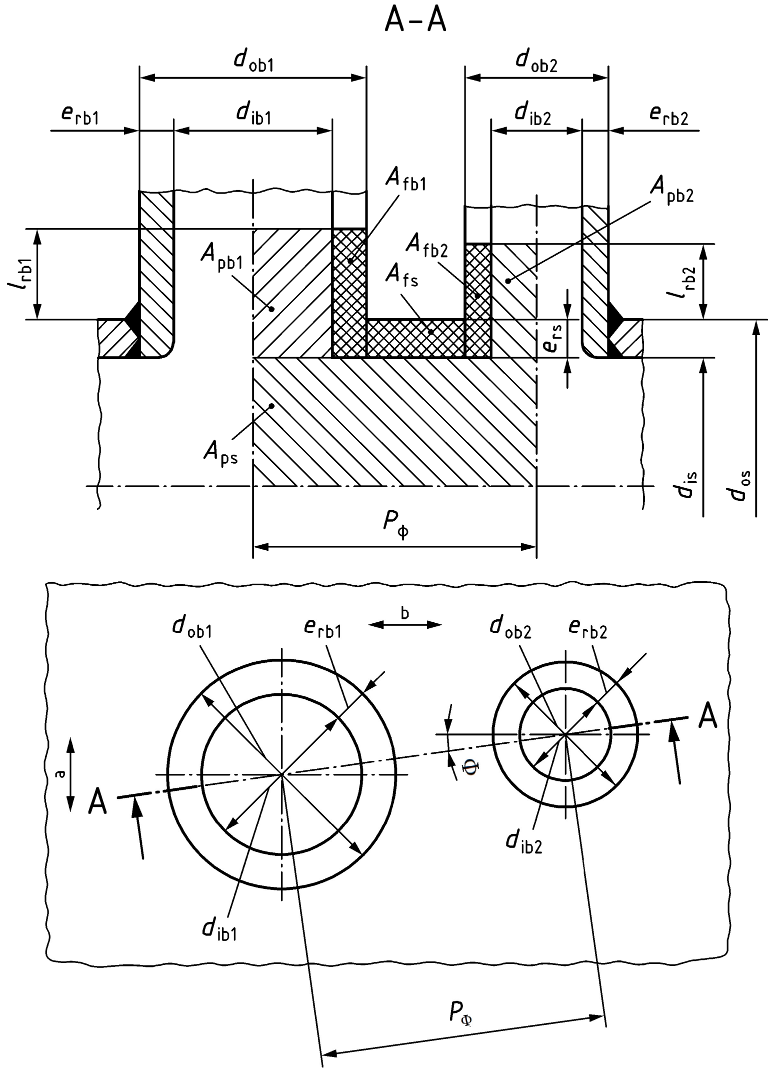
l_{rs} effective length of main body contributing to reinforcement

$\Psi \leq 45°$

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

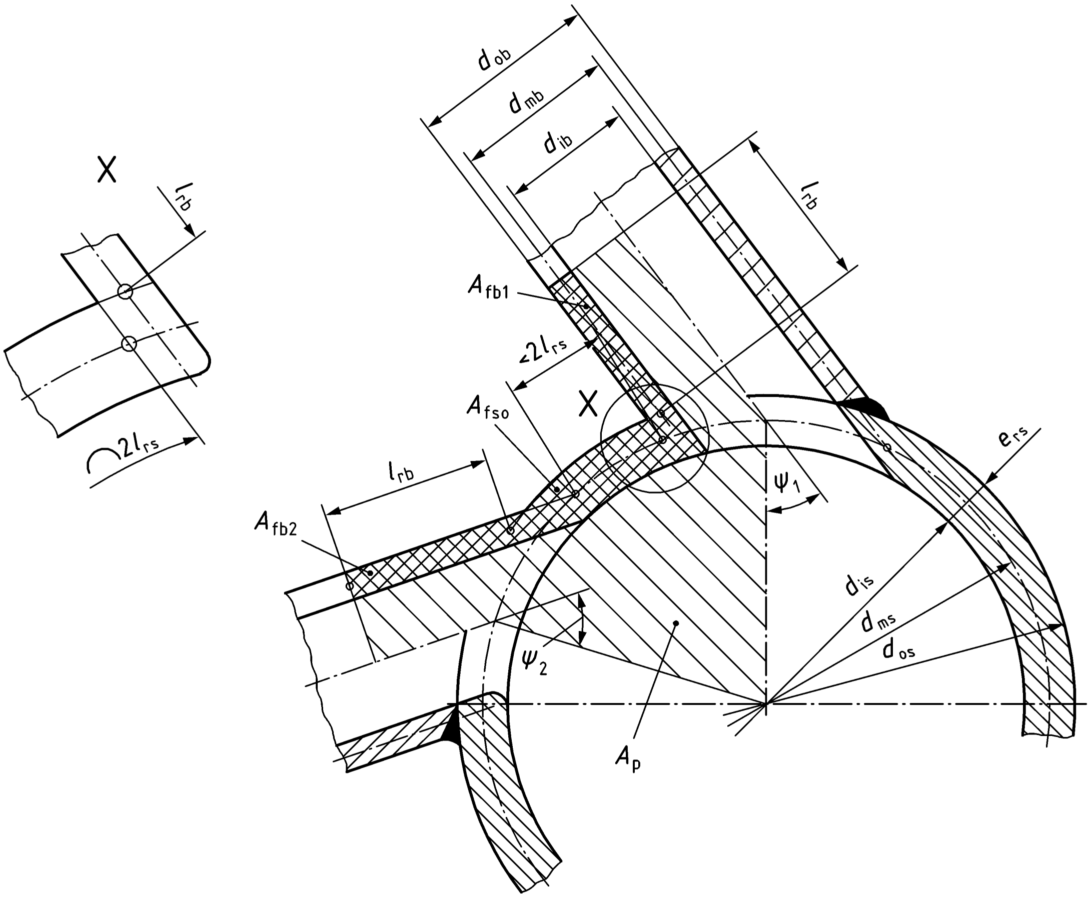
P_{Φ} centre-to-centre distance of adjacent openings, staggered by the angle Φ referring to centre of wall

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 $v = 1$ 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:

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

The efficiency shall be:

$$v_\mathrm{b} = \frac{d_\mathrm{is} \left(A_\mathrm{fs} + A_\mathrm{fb} \right)}{2 e_\mathrm{rs} A_\mathrm{p}} \leq 1 \tag{34}$$

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:

$$f_\mathrm{a} = \frac{p_\mathrm{c} \left(2 A_p + A_\mathrm{fs} + A_\mathrm{fb} \right)}{2 \left(A_\mathrm{fs} + \frac{f_\mathrm{b}}{f_\mathrm{s}} A_\mathrm{fb} \right)} \leq f_\mathrm{s} \tag{35}$$

In this case the efficiency shall be:

$$v_\mathrm{b} = \frac{d_\mathrm{is} \left(A_\mathrm{fs} + \frac{f_\mathrm{b}}{f_\mathrm{s}} A_\mathrm{fb} \right)}{e_\mathrm{rs} \left(2 A_\mathrm{p} + A_\mathrm{fb} - \frac{f_\mathrm{b}}{f_\mathrm{s}} A_\mathrm{fb} \right)} \leq 1 \tag{36}$$

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:

$$f_\mathrm{a\,I} = p_\mathrm{c} \left(\frac{A_\mathrm{p\,I}}{A_\mathrm{fs\,I} + A_\mathrm{fb\,I} + 0{,}7\, A_\mathrm{fp\,I}} + \frac{1}{2} \right) \leq f_\mathrm{s} \tag{37}$$

and for area II

$$f_\mathrm{a\,II} = p_\mathrm{c} \left(\frac{A_\mathrm{p\,II}}{A_\mathrm{fs\,II} + A_\mathrm{fb\,II} + 0{,}7\, A_\mathrm{fp\,II}} + \frac{1}{2} \right) \leq f_\mathrm{s} \tag{38}$$

8.3.3.3.3 If the design stress of the branch material or the material of the additional reinforcing pad is less than that of the shell, the strength condition for area I shall be:

$$\left(f_\mathrm{s}-\frac{p_\mathrm{c}}{2}\right)A_\mathrm{fs\,I}+\left(f_\mathrm{b}-\frac{p_\mathrm{c}}{2}\right)A_\mathrm{fb\,I}+\left(f_\mathrm{p}-\frac{p_\mathrm{c}}{2}\right)0{,}7\,A_\mathrm{fp\,I}\geq p_\mathrm{c}\,A_\mathrm{p\,I} \tag{39}$$

and for area II.

$$\left(f_\mathrm{s}-\frac{p_\mathrm{c}}{2}\right)A_\mathrm{fs\,II}+\left(f_\mathrm{b}-\frac{p_\mathrm{c}}{2}\right)A_\mathrm{fb\,II}+\left(f_\mathrm{p}-\frac{p_\mathrm{c}}{2}\right)0{,}7\,A_\mathrm{fp\,II}\geq p_\mathrm{c}\,A_\mathrm{p\,II} \tag{40}$$

8.3.3.4 Cylindrical shells with a branch not radially arranged

For cylindrical shells where the branch is not arranged in the radial direction (see Figure 13), but at an angle Ψ, the higher loading can occur in the cross-section of Figure 13 or in the longitudinal section of Figure 13. In both cases the strength condition as per Formula (33) shall apply, with the areas A_p, A_fs and A_fb shown in the respective Figures to be used in the calculation. The lengths contributing to the reinforcing pad (effective lengths) shall only be used in the calculation of the shell in accordance with Formula (18) or of the branch connection according to Formula (19) or (20) respectively.

The wall thickness of the branch e_rb shall not exceed the wall thickness e_rs of the shell.

8.3.4 Design of adjacent openings and branch connections

8.3.4.1 General

Adjacent openings shall be calculated additionally as isolated openings.

8.3.4.2 Condition of adjacent openings and branches

The calculation shall only be made if the condition for isolated openings or branch connections laid down in 8.1.3 is not met for adjacent openings or branches.

8.3.4.3 Shell with lower design stress than the branches

For adjacent openings or branch connections, the strength shall be calculated for a cross-section with an angle Φ for the shell generating line in accordance with Figure 14. The strength condition given by Formula (41) shall be met:

$$f_\mathrm{a\Phi}=\frac{p_\mathrm{c}}{2}\,\frac{2\,A_\mathrm{p0}\,\dfrac{1+\cos^2\Phi}{2}+2\,A_\mathrm{p1}+2\,A_\mathrm{p2}}{A_\mathrm{fs0}+A_\mathrm{fb1}+A_\mathrm{fb2}}+\frac{p_\mathrm{c}}{2}\leq f_\mathrm{s} \tag{41}$$

Diagonal or circumferential pitches shall be calculated as a longitudinal pitch in accordance with Figure 14 with a distance P_Φ. In this case the pressure area 2 A_p0 shall be corrected by the factor $((1 + \cos^2\Phi)/2)$ in the strength condition in accordance with Formula (44).

The efficiency shall be:

$$v_\mathrm{m}=\frac{d_\mathrm{is}}{e_\mathrm{rs}}\,\frac{A_\mathrm{fs0}+A_\mathrm{fb1}+A_\mathrm{fb2}}{2\,A_\mathrm{p0}\,\dfrac{1+\cos^2\Phi}{2}+2\,A_\mathrm{p1}+2\,A_\mathrm{p2}}\leq 1 \tag{42}$$

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.

8.3.4.4 Branches with equal or lower design stress than the shell

If the design stress of one or both branches is less than that of the shell, the condition given by Formula (43) shall be met:

$$f_{a\Phi} = \frac{p_c}{2} \frac{2\,A_{p0}\,\frac{1+\cos^2\Phi}{2} + 2\,A_{p1} + 2\,A_{p2} + A_{fs0} + A_{fb1} + A_{fb2}}{A_{fs0} + \frac{f_{b1}}{f_s} A_{fb1} + \frac{f_{b2}}{f_s} A_{fb2}} \le f_s \qquad (43)$$

In this case, the efficiency shall be:

$$v_m = \frac{d_{is}}{e_{rs}} \frac{A_{fs0} + \frac{f_{b1}}{f_s} A_{fb1} + \frac{f_{b2}}{f_s} A_{fb2}}{2\,A_{p0}\,\frac{1+\cos^2\Phi}{2} + 2\,A_{p1} + 2\,A_{p2} + A_{fb1} + A_{fb2} - \frac{f_{b1}}{f_s} A_{fb1} - \frac{f_{b2}}{f_s} A_{fb2}} \le 1 \qquad (44)$$

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.

8.3.4.5 Adjacent branches in the circumferential direction

For non-radial adjacent branches arranged on the circumference in accordance with Figure 15, the calculation procedure shall be analogous to radial branches. In this case the correction factor ($(1 + \cos^2\Phi)/2$) shall be replaced by the factor 1.

9 Ends

9.1 Unstayed dished heads without openings

NOTE In case of unstayed dished heads with openings, see EN 12952-3:2011, 10.2.

9.1.1 Unstayed dished heads under internal pressure

The minimum thickness of unstayed dished heads without openings shall be in accordance with the requirements of Formulae (45) and (46):

$$e_s = e_{cs} + c_1 + c_2 \qquad (45)$$

$$e_{cs} = \frac{p_c\, d_o\, C}{2\,f} \qquad (46)$$

In addition, the thickness of a torispherical head shall be not less than that given by Formula (47):

$$e_{cs} = \frac{p_c\, r_{is}}{2\,f - 0{,}5\,p_c} \qquad (47)$$

The shape factor C for unstayed dished heads without openings shall be as given in Figure 16. However, the limiting conditions given in 9.1.2 shall apply.

9.1.2 Limiting conditions

The limiting conditions shall be for:

a) Hemispherical heads

$0{,}005\ d_o \le e_{cs} \le 0{,}16\ d_o$;

b) Ellipsoidal heads

$0{,}005\ d_o \le e_{cs} \le 0{,}08\ d_o$ and

$h_c \ge 0{,}18\ d_o$;

c) Torispherical heads

$0{,}005\ d_o \le e_{cs} \le 0{,}08\ d_o$ and

$r_{ik} \ge 0{,}1\ d_o$ and

$r_{ik} \ge 2\ e_{cs}$ and

$r_{is} \le d_o$ and

$h_c \ge 0{,}18\ d_o$;

or

$0{,}01\ d_o \le e_{cs} \le 0{,}03\ d_o$ and

$r_{ik} \ge 0{,}1\ d_o$ and

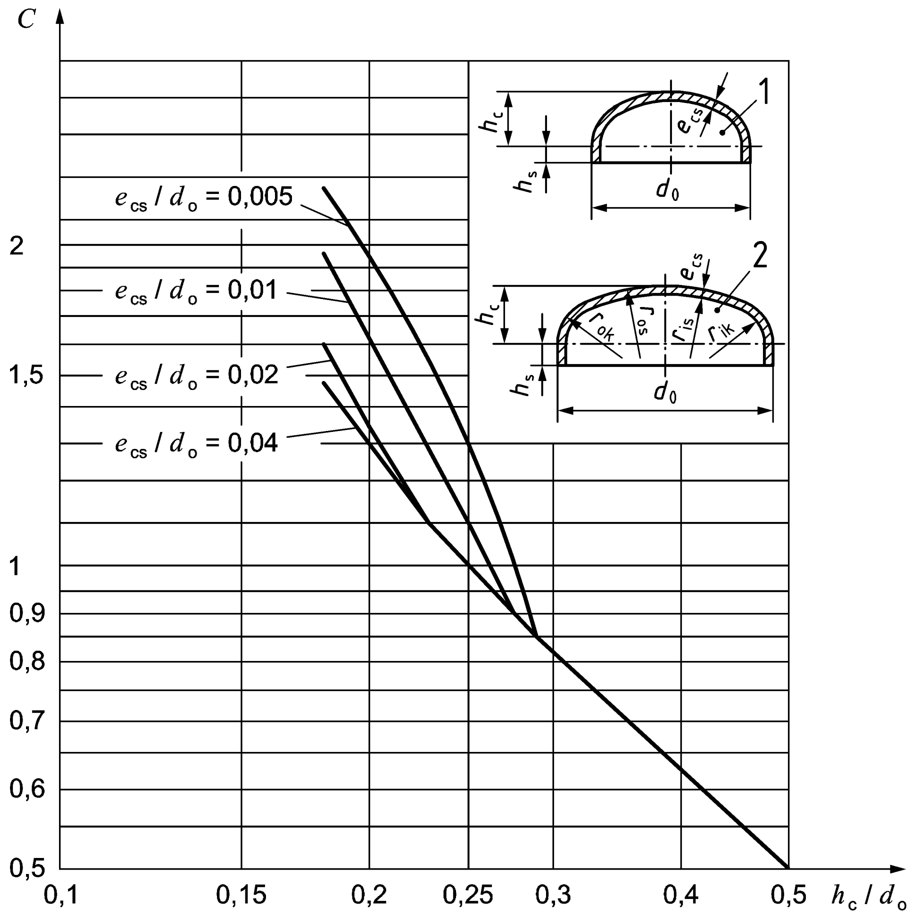
$h_c \ge 0{,}18\ d_o$;

or

$0{,}02\ d_o \le e_{cs} \le 0{,}03\ d_o$ and

$r_{ik} \ge 0{,}1\ d_o$ and

$0{,}18\ d_o \le h_c \le 0{,}22\ d_o$.



Key

C	shape factor for unstayed dished heads without openings
d_o	nominal outside diameter
e_{cs}	calculated wall thickness of the main body (cylindrical or spherical shells or dished ends) without allowances
h_c	depth of curvature of dished head (with knuckle, without cylindrical skirt)
h_s	height of cylindrical skirt of dished end
r_{ik}	inside radius of dishing of dished ends or of knuckle or relief groove of flat ends
r_{is}	inside corner radius of dished end or spherical shell
r_{ok}	outside radius of knuckle of dished end
r_{os}	outside corner radius of dished end or spherical shell
1	ellipsoidal head
2	torispherical head

Figure 16 — Shape factor *C* for unstayed dished heads without openings

9.1.3 Unstayed dished heads under external pressure

The calculation pressure p_c shall be the lower of the values obtained from Formulae (48) and (49):

$$p_c = \frac{e_{cs}\ R_{p\,0,2tc}}{1,2\ r_{os}} \tag{48}$$

$$p_c = \frac{0{,}8\,E}{9 + 0{,}006\left(\frac{r_{os}}{e_{cs}}\right)}\left(\frac{e_{cs}}{r_{os}}\right)^2 \qquad (49)$$

In addition, the thickness of torispherical and ellipsoidal heads under external pressure shall be not less than 1,2 times the thickness required for a head of the same shape subject to internal pressure (see 9.1.1).

9.2 Flat unstayed removable closures

The thickness shall be determined in accordance with Formula (50) with d_i taken as indicated in Figure 17.

$$e_{ch} = C_1 y\ d_i \sqrt{p_c / f} \qquad (50)$$

When the closure is external, C_1 shall be taken as 0,41, except where closures of the type shown in Figure 17 d) are used, where the bolting adds to the bending moment in the plate. In such cases, the values for C_1 given in Table 1 shall apply:

Table 1 — Values for C_1

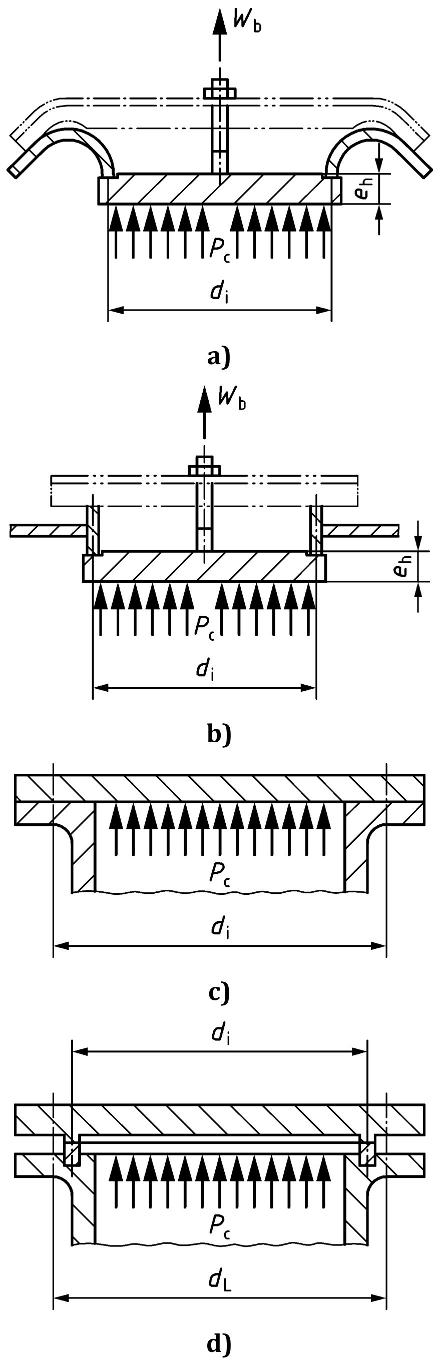
d_L/d_i	C_1
1,0	0,45
1,1	0,50
1,2	0,55
1,3	0,60

When internal doors of the type shown in Figure 17 a) and b) are used, factor C_1 shall be taken as 0,45.

Account shall also be taken of the additional bending moment in the plate caused by the bolting W_b. If no calculation is carried out to determine the exact bending load caused by the bolting then p_c shall be multiplied by a load factor of minimum 1,5.

For circular plates the factor y is defined as 1. For oval ends with major and minor axes a and b the factor y is given in Figure 22. For d_i minor axis b shall be used.

NOTE Other design for covers are accepted provided calculation should be performed according to a recognized standard e.g. EN 13445–3:2014.



Key

d_i calculation diameter of the pressurized area

p_c calculation pressure

e_h wall thickness of the plate (applicable for Figures a) and b) only)

d_L bolt circle diameter

W_b load by bolting torque

Figure 17 — Flat unstayed removable closures

9.3 Unstayed flat plates

Any unstayed flat plates up to DN 600 can be used following the welding details and calculation requirements as specified in EN 12952-3:2011, 10.3.

10 Supported flat plates, stays and stiffeners

10.1 Breathing space for flat plates

A boiler incorporates items in its design (e.g. furnace, tube nests) that operate at different temperatures to each other and to the shell and, because of this, differential expansion will occur.

This differential expansion is normally transferred to the boiler end plates and tube plates, which results in displacement and the boiler is said to “breathe”. In order to provide the necessary flexibility, breathing spaces are required.

Stays shall give breathing space around the furnace in the boiler end plate and tube nests and equally divide the unstayed areas.

The following requirements for breathing spaces shall be followed:

— Breathing space between furnace and tube nests (see “c” in Figure 18) shall be a minimum of 50 mm or 5 % of the outside diameter of the shell, whichever is the larger, but need not to be more than 100 mm.

  The breathing space c may be reduced by 15 mm in the case of standard corrugated furnace (corrugation depth 50 mm) and by 25 mm in the case of deep corrugated furnace (corrugation depth ≥ 75 mm). The same requirement applies at the weld end of the furnace.

— Breathing space between furnace and shell (see “a” in Figure 18) shall be in accordance with Table 2 and Table 3 respectively, but shall be not less than 50 mm or, for bowling hoop furnaces tubes, not less than 75 mm.

Table 2 — Breathing space between furnace and shell if e_h ≤ 25 mm

Design	Length between boiler end plates L_b m	Breathing space		
		Nominal percentage of outside diameter %	maximum mm	minimum mm
Set-in end plates	L_b ≤ 5,5 or exception of footnote [a]	5	100	50
	5,5 < L_b ≤ 6	5,5	110	55
	6 < L_b ≤ 6,5	6	120	60
	6,5 < L_b ≤ 7	6,5	130	65
Flanged ends	any length	5	100	50

[a] Exception: If the design is in accordance with EN 12953–1:2012, 3.7 Figure 2 (construction with internal reversal chamber), the limitation of the length between the boiler end plates shall not be applied.

Table 3 — Breathing space between furnace and shell when the thickness of the end plates exceeds 25 mm

Design	**Length between boiler end plates**	**Breathing space**		
	L_b m	Nominal percentage of outside diameter %	maximum mm	minimum mm
Set-in end plates	$L_b \leq 5{,}5$	6,5	130	65
	$5{,}5 < L_b \leq 6$	7	140	70
	$6 < L_b \leq 6{,}5$	8	150	75
	$6{,}5 < L_b \leq 7$	10	160	80
Flanged ends	any length	5	100	50

— In the case of reverse flame boilers, the breathing space at the front end between the furnace and tube nests shall be not less than 50 mm. Additionally, the sum of this breathing space and the breathing space formed by the outer annular area of the furnace rear plate shall be not less than 50 mm or 5 % of the shell inside diameter, whichever is the larger, with a maximum of 100 mm.

— Breathing space between smoke tubes and wrapper plates (see “d” in Figure 18) shall be a minimum of 50 mm or 3 % of the outside diameter of the shell, whichever is the larger, but need not to be more than 100 mm.

Reduction of breathing space:

It is possible that the breathing space “d” is less than required in the case of cylindrical reversal chamber clear widths ≤ 650 mm, however, the minimum breathing space of 50 mm shall be maintained in any case.

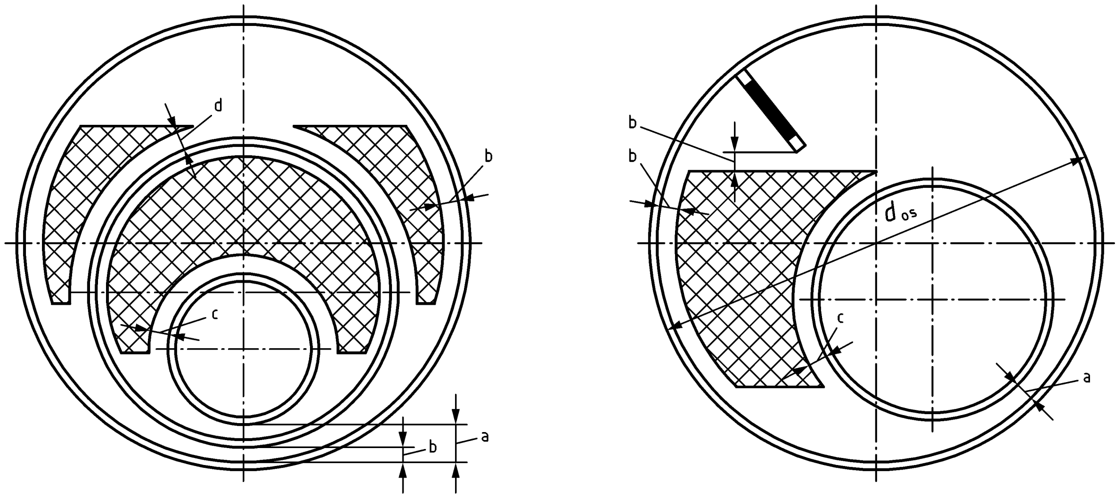
— Breathing space between furnaces shall be not less than 120 mm.

— Breathing spaces between gusset or link stays and furnaces shall be not less than 200 mm, except for a shell outside diameter less than 1 400 mm or a furnace length less than 3 000 mm, in which case the breathing
spaces shall be not less than 150 mm.

— All other breathing spaces (see “b” in Figure 18, e.g. smoke tubes-shell b, wrapper plates-shell b, gusset stay-smoke tubes b etc.) shall be a minimum of 50 mm or 3 % of the shell outside diameter, whichever is the larger, but need not to be more than 100 mm.

— The recommendation of minimum breathing spaces does not refer to the distance between ring stiffeners - smoke tubes and between ring stiffeners – shell if cleaning and inspection are not impaired.

— For heat recovery boilers without furnace, the requirements listed above are not applicable.



Key

d_{os} nominal outside diameter of main body

a, b, c, d breathing spaces (see 10.1).

Figure 18 — Examples for breathing spaces

10.2 Stayed flat surfaces

10.2.1 General

Flat plates (e.g. reversal chamber tube plate, front tube plate and rear tube plate) shall be adequately supported by using bar stays, stay tubes, gusset stays, or a combination of these.

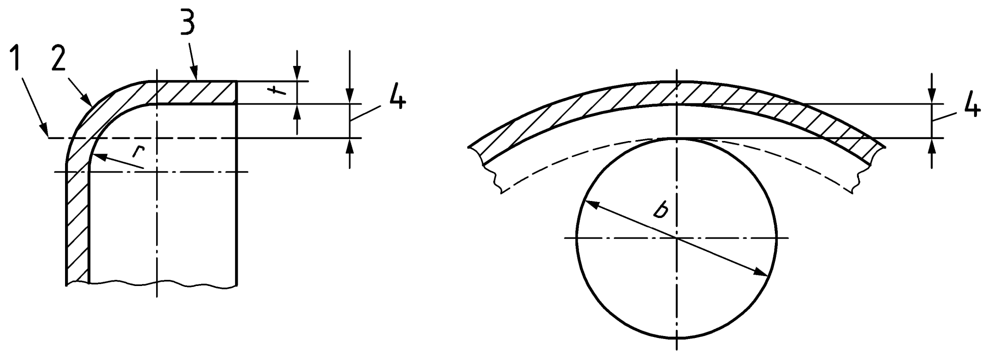
NOTE In order to keep the thickness of the flat plate as small as possible it is recommended that an appropriate number of stays be provided.

10.2.2 Radius of flange

Where flat plates are flanged, the inside radius of flanging shall be at least 1,3 times the thickness of the plate, but not less than 30 mm.

10.2.3 Point of support

Where the curvature of the flange (dished ends) is a point of support, the point of support shall be taken at a line either half the distance between the inside of the shell and the commencement of curvature, or at a line 2,5 times the thickness of the plate measured from the inside of the shell or wrapper plate, whichever is the lesser (see Figure 19). Where a flat plate is welded directly to a shell or wrapper plate, the point of support shall be taken at the inside of the shell or wrapper plate (see Figures 20 and 21).



Key

b diameter of the calculation area

t thickness of the plate

r radius of the knuckle

1 point of support

2 flanged end

3 shell or wrapper plate

4 2,5 × t or 0,5 × r, whichever is the lesser

Figure 19 — Point of support of a flanged end

10.2.4 Thickness

The thickness of those portions of flat plates supported by stays shall be determined from Formulae (51) and (52):

$$e_h = e_{\text{ch}} + c_1 + c_2 \qquad (51)$$

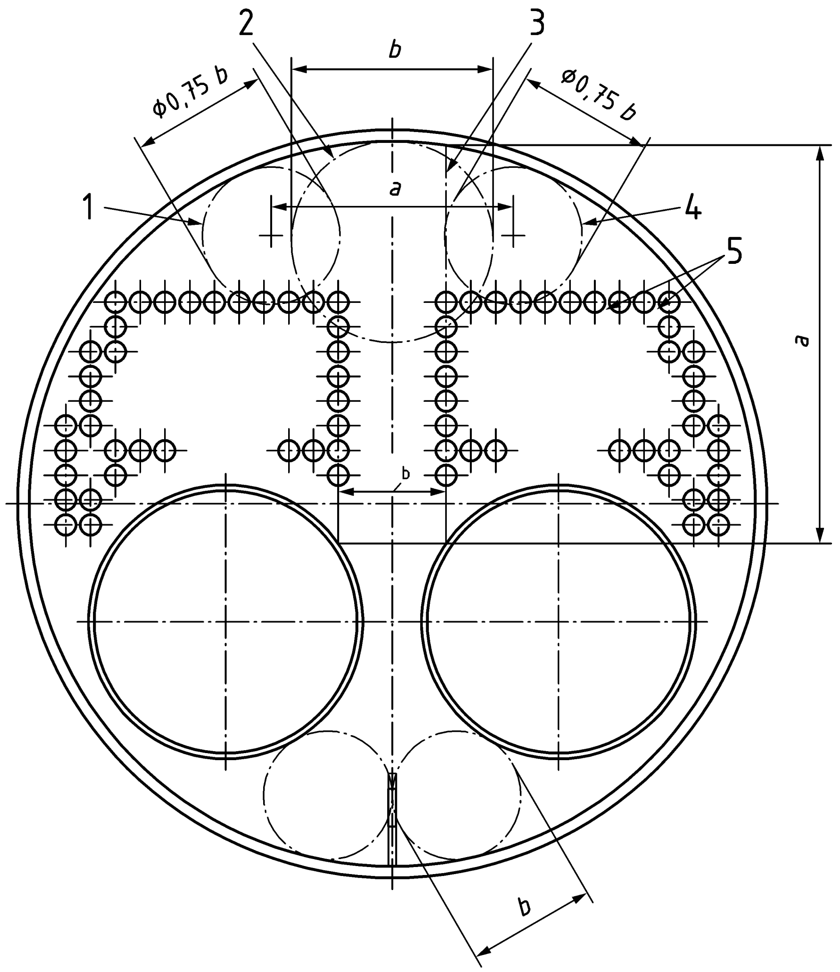
$$e_{\text{ch}} = C_4\, b\, y \sqrt{\frac{p_{\text{c}}}{f}} \qquad (52)$$

For areas enclosed by circles which pass through four or more evenly distributed points of support, *y* shall be taken as 1.

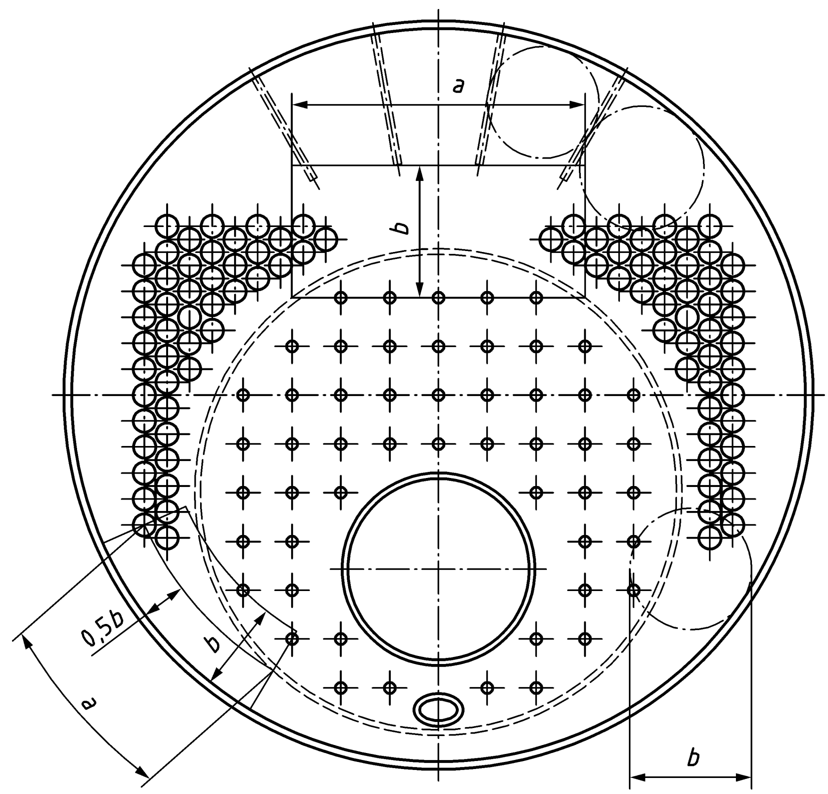
For areas enclosed by circles which pass through three points of support (such that the centre of a sub-circle which passes through at least two points of support in accordance with Figure 20 or 21 with a diameter equal to 0,75 times the diameter of the main circle lies outside the main circle) *y*, taken from Figure 22, shall be determined using dimensions *a* and *b* as indicated in Figure 20 or 21. Where the main circle passes through three points of support, not more than two of them shall lie on one side of any diameter. In this case *y* shall be taken as not less than 1,1. For annular areas, e.g. areas supported only by shell and furnace, *y* shall be taken as 1,56.

For unstayed areas of rectangular shape, the dimensions *a* and *b* shall be as indicated in Figure 20.

Three or more adjacent stay tubes can be considered as one point of support, in which case the circle shall at least cross the centre of 2 smoke tubes and touch a third one.



a) Example for main and sub-circles (twin furnace boiler)



b) Example for main and sub-circles / rectangular areas (single furnace boiler)

Key

a dimension of the calculation area

b dimension of the calculation area

1 sub-circle

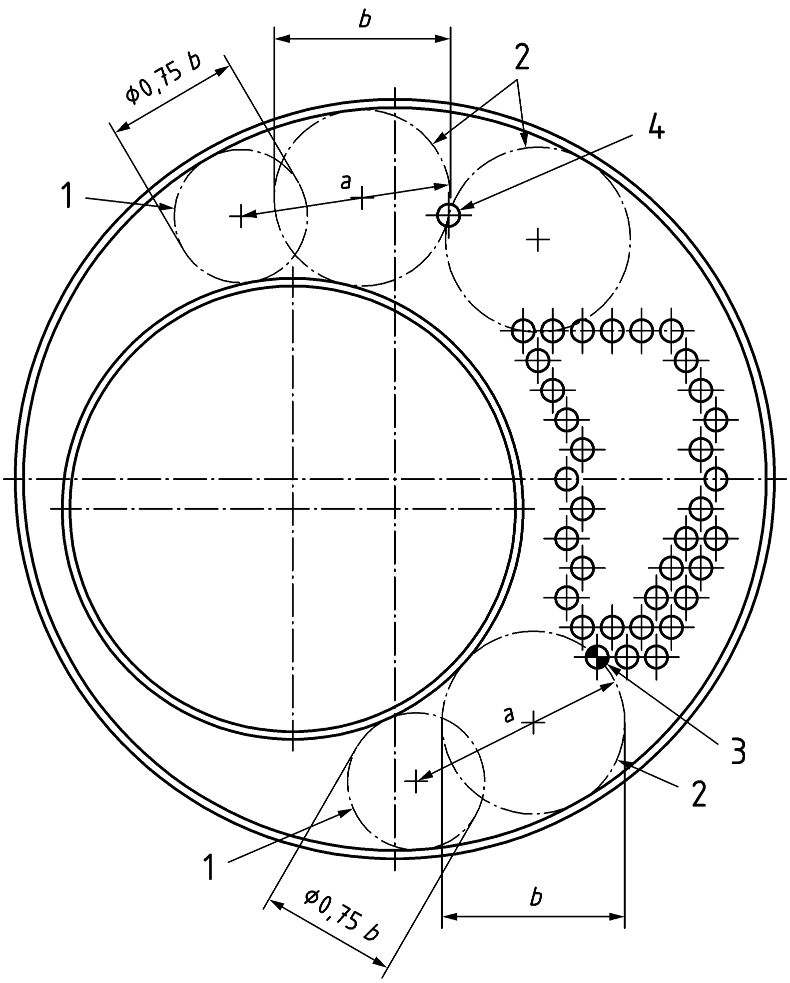
2 main circle, diameter *b*

3 unstayed rectangular area (see 10.2.3)

4 sub-circle

5 smoke tubes

Figure 20 — Example for main and sub-circles / rectangular areas



Key

a dimension of the calculation area

b dimension of the calculation area

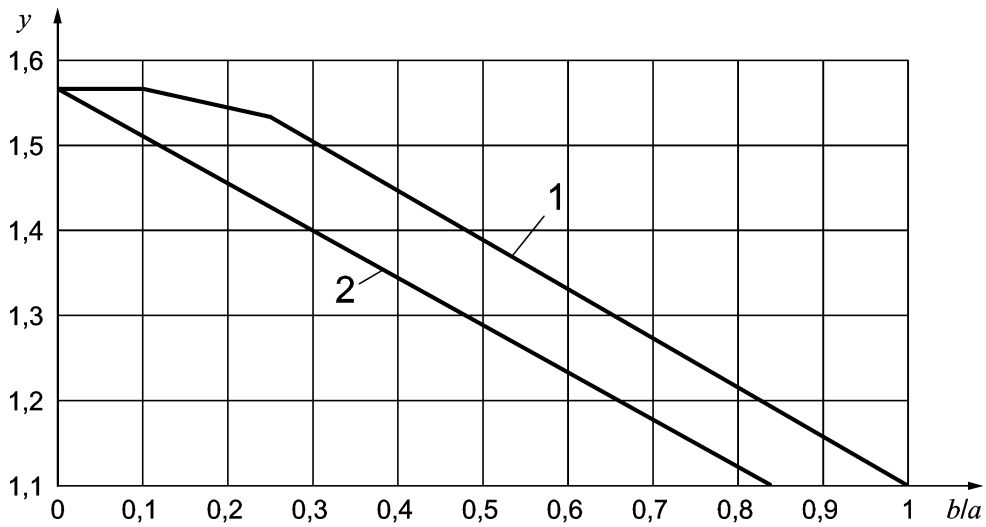
1 sub-circle

2 main circles

3 reinforced smoke tube

4 bar stay / tube stay

Figure 21 — Example for main and sub-circles (single furnace boiler)



Key

y factor determined using the ratio *b/a*

a dimension of the calculation area

b dimension of the calculation area

1 rectangular areas

2 elliptical areas

NOTE See 10.2.4.

Rectangular areas

$0,00 < b/a \leq 0,10$	$y = 1,56$
$0,10 < b/a \leq 0,25$	$y = 1,56 - 0,04 * (b/a - 0,10) / 0,15$
$0,25 < b/a \leq 1,00$	$y = 1,52 - 0,42 * (b/a - 0,25) / 0,75$

Elliptical areas

$0,00 < b/a \leq 0,83$	$y = 1,56 - 0,46 * b/a / 0,83$
$0,83 < b/a \leq 1,00$	$y = 1,1$

Figure 22 — Determination of factor *y*

10.2.5 Values of constant C_4

Where various forms of support apply to the portion of flat plate under consideration, the constant C_4 shall be the mean of the values for the respective methods adopted.

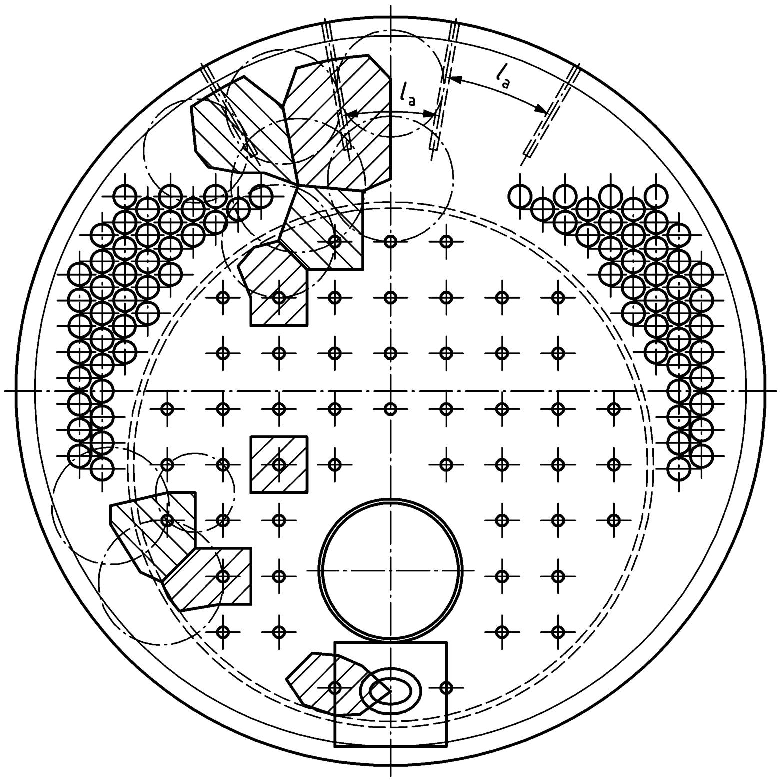
End plates, set on to the shell are not described in this Standard. However, on specific cases set on plates can be used for low pressure boilers (LPB) as defined in EN 12953-1. Details for calculation and welding are described in EN 14394.

The values of constant C_4 in Formula (52) shall be in accordance with Table 4.

Table 4— Values for constant C_4

Component	Values for C_4
Freely supported plates with locking devices, e.g. manhole covers	0,45
Inset flat end plates, full penetration welded from one side	0,45
Plates which are bolted along their circumference:	
when the ratio D_L/D_b = 1	0,45
when the ratio D_L/D_b = 1,3	0,6
When the ratio D_L/D_b is between 1 and 1,3, the values of the constant shall be determined by linear interpolation.	
Flanged end plate	0,32
Gusset stays	0,3
Unstayed tube nest with plain tubes welded at both ends. The loaded area shall at least cross the centre of 2 smoke tubes and touch a third one.	0,3
Plain furnaces tubes less than 6 m long	0,3
Plain furnaces tubes 6 m to 8 m long	0,32
Corrugated furnaces tubes with corrugation depths ≤ 50 mm	0,32
Corrugated furnaces tubes with corrugation depths > 50 mm:	
with a length ≤ 6 m	0,35
with a length > 6 m	0,37
Bowling hoop furnaces tubes	0,35
Isolated plain bar stays or isolated stay tube	0,45
Non-isolated plain bar stays or non-isolated stay tubes	0,39
Bar stays or stay tubes shall be considered isolated if the centre distance is more than 200 mm between stays	
Bar stays with washers type 1	0,35
Bar stays with washers type 2	0,33
Reversal chamber bar stays and stay tubes (see Figure 29)	0,39
Reversal chamber access openings welded from both sides (see Figure 28)	0,3
Reversal chamber access opening (where it is not possible to effect back weld) (see Figure 28)	0,45
Set-in end plates welded to the shell from both sides with end plate thickness to shell thickness ratios e_h/e_s:	
≤ 1,4	0,33
> 1,4 ≤ 1,6	0,36
> 1,6 ≤ 1,8	0,39
> 1,8 ≤ 2,0	0,42
Flat surface of reversal chamber reinforced by stiffeners continuously welded above or flush stiffeners equipped with waterways (see Figure 29 a) to 29 e)) and with a stiffener height of between six and eight times its thickness.	0,4
Portion of unheated end plates containing a manhole with reinforcing ring (see Figure 34), when the distance from the edge of the manhole ring to the edges of the furnace, smoke tubes or shell is not more than four times the end plate thickness (see Figure 30).	0,27
If the distance from the edge of the manhole ring to the edges of the furnace, smoke tubes or shell exceeds four times the end plate thickness, the manhole is ignored, and the constant C_4 shall be determined from the mean of the values for the methods of attachment given in this Table.	

Dimensions in millimetres



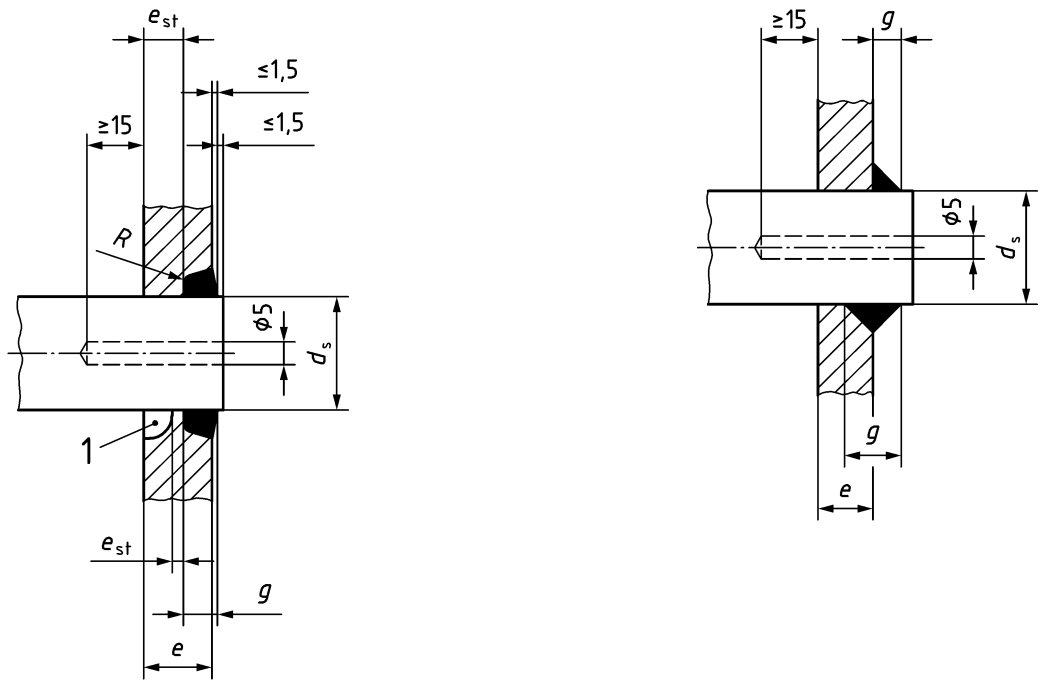
Key

l_a distance between centre lines of stays

NOTE See 10.2.9.

Figure 23 — Example for pressure loaded areas

Dimensions in millimetres



a) Heated **b) Unheated**

Key

d_s diameter of stay

e wall thickness

e_{st} remaining thickness after weld preparation and cooling groove

g weld connection length to the bar stays

R radius of the weld preparation

1 cooling groove

$g \geq 0{,}35 d_s$ or exact calculation

$e_{st} \leq 10$

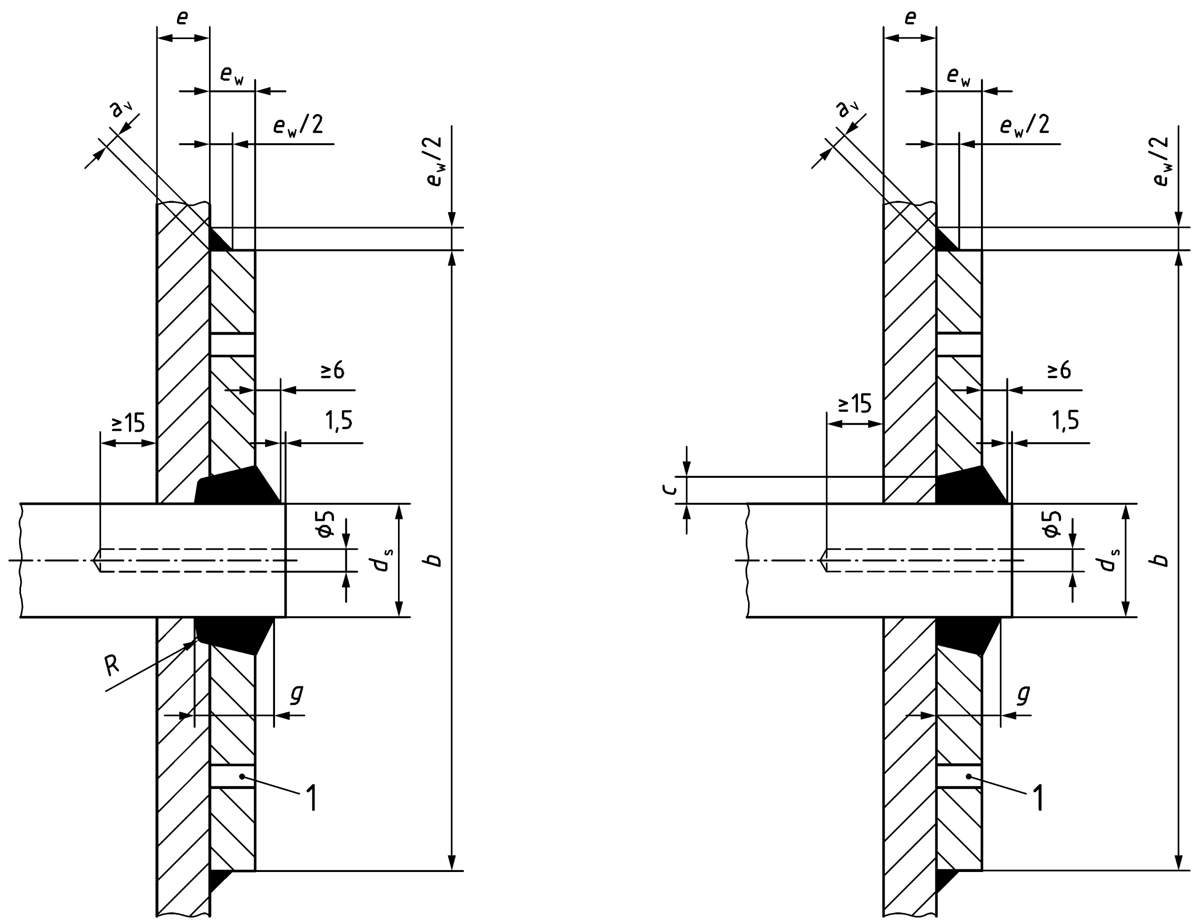
heated: flue gas temperature > 700°C

unheated: flue gas temperature ≤ 700°C

Where *e* is less than 0,35 d_s, the form of construction shown in Figure 25 shall be used or exact calculation shall be performed.

Figure 24 — Permitted weld details of bar stays without washers

Dimensions in millimetres



Key

d_s diameter of stay

e wall thickness

a_v weld thickness

b washer diameter

e_w washer thickness

g weld connection length to the bar stays

R radius of the weld preparation

1 vent

$g \geq 0{,}35d_s$

$a_v > 0{,}35e_w$

Type 1: $b \geq 3{,}5d_s$

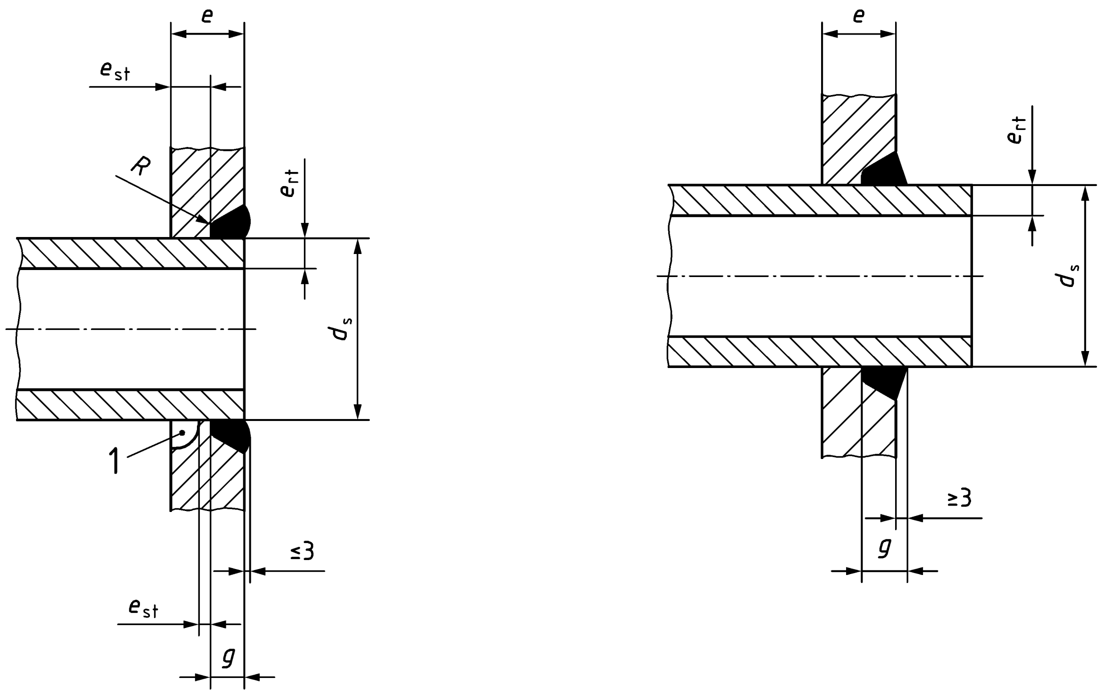
Type 2: b = 2/3 pitch of stays

c = (0,15 d_s) or 8 mm whichever is the greater

NOTE $e_w \geq 2/3$ e

Figure 25 — Permitted weld details of bar stays with washers (unheated)

Dimensions in millimetres



a) Heated **b) Unheated**

Key

d_s diameter of stay tube

e wall thickness

e_{rt} actual tube wall thickness without allowances

e_{st} remaining thickness after weld preparation and cooling groove

g weld connection length to the stay tubes

R radius of the weld preparation

1 cooling groove

$g \geq 1{,}25 e_{rt}$ or exact calculation

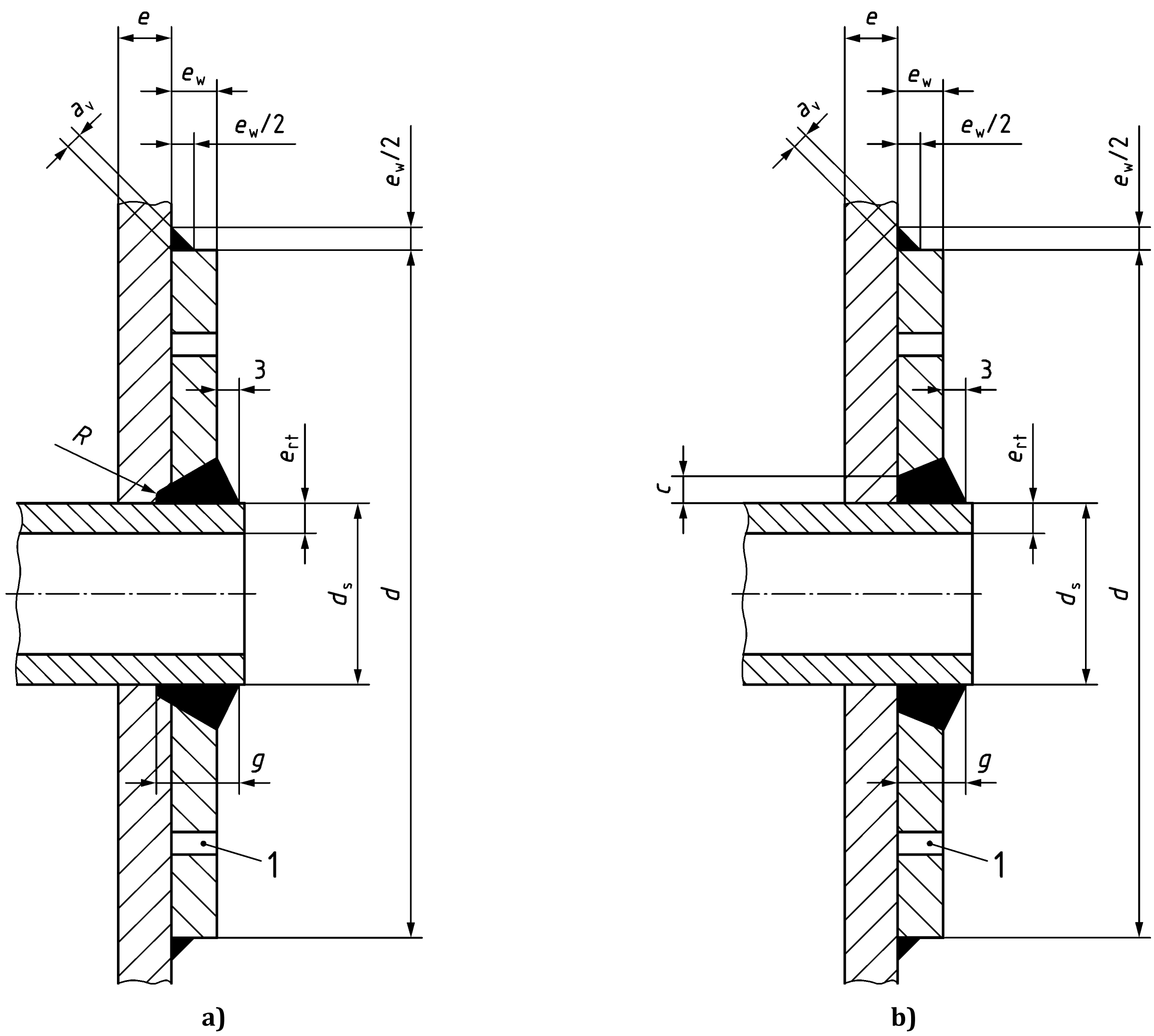
$e_{st} \leq 10$

heated: flue gas temperature > 700°C

unheated: flue gas temperature ≤ 700°C

Figure 26 — Permitted weld details of stay tubes without washers

Dimensions in millimetres



Key

d_s diameter of stay tube

e wall thickness

e_{rt} actual tube wall thickness without allowances

a_v weld thickness

d washer diameter

e_w washer thickness

g weld connection length to the stay tubes

R radius of the weld preparation

1 vent

$g \geq e_{rt}$

$a_v > 0{,}35e_w$

Conditions for d:

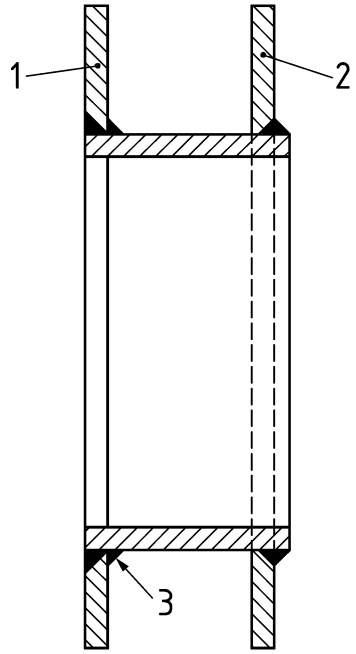
- Type 1: $d \geq 3{,}5d_s$
- Type 2: d = 2/3 pitch of stays

c = ($0{,}15d_s$) or 8 mm whichever is the greater

NOTE $e_w \geq 2/3$ e where e_w is less than 0,35 d_s the form of construction shown as in Figure 27 a) needs to be used

Figure 27 — Permitted weld details of stay tubes with washers (unheated)

Dimensions in millimetres



Key

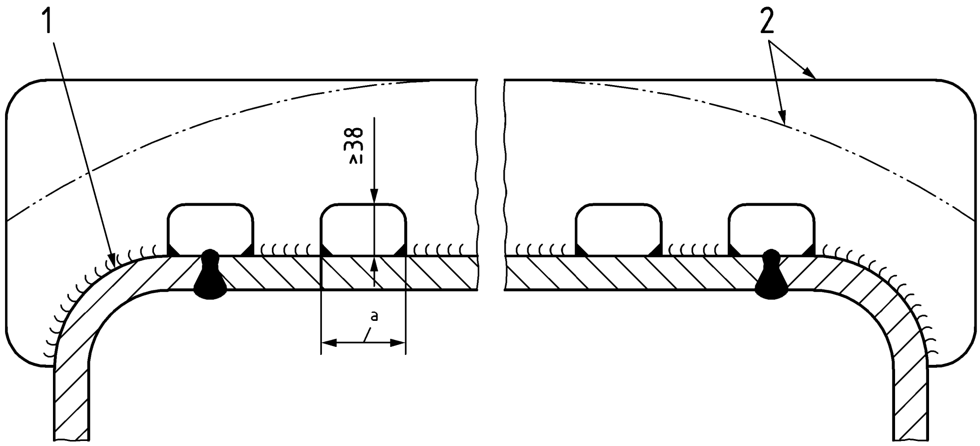
1 combustion chamber plate

2 back end plate

3 seal weld

Figure 28 — Access opening for wet back boilers

Dimensions in millimetres



Key

1 may be welded for fixed attachment

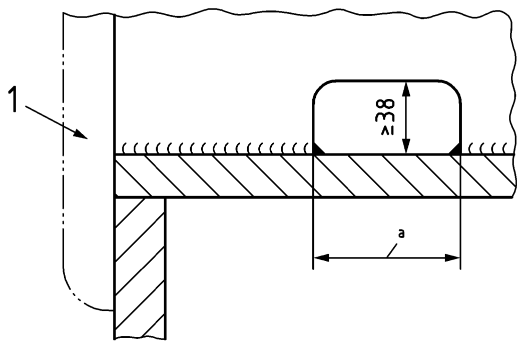
2 alternative shape of girder (see the note)

a width of waterway

NOTE Girders may be shaped to either the full or the thin chain line shown.

a) Method of welding girder to a reversal chamber with flanged ends

Dimensions in millimetres

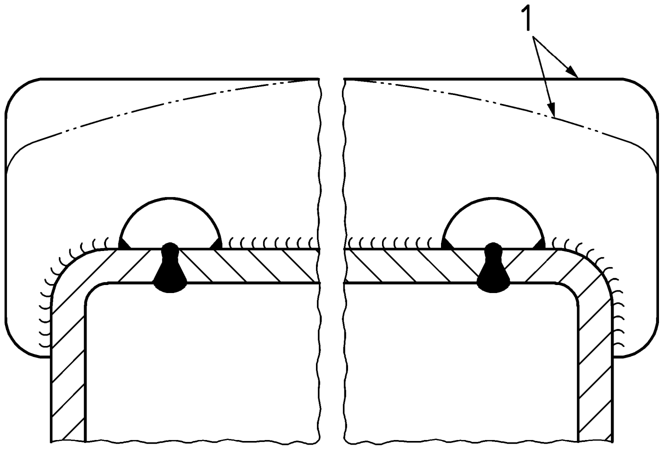


Key

1 girder may be carried over the ends of the reversal chamber

a width of waterway

b) Method of welding girder to a reversal chamber with flat ends

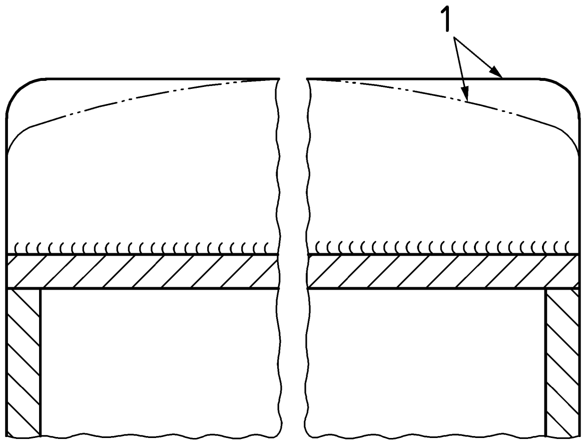


Key

1 alternative shape of girder

NOTE Girders may be shaped to either the full or the thin chain line shown.

c) Welded-on girder to a reversal chamber having flanged tube plate and back plate

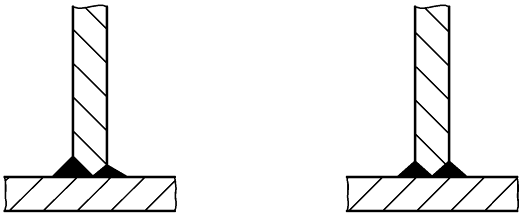


Key

1 alternative shape of girder

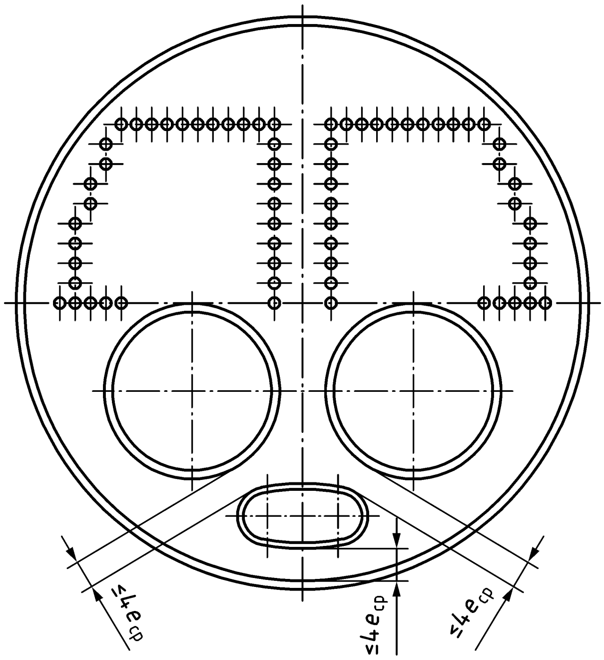
NOTE Girders may be shaped to either the full or the thin chain line shown.

d) Welded-on girder to a reversal chamber having square corners

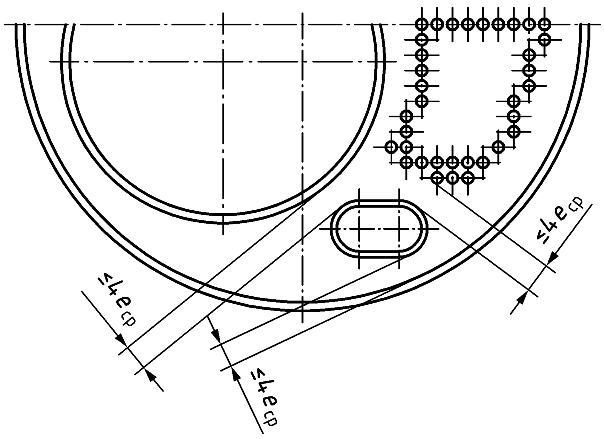


e) Alternative methods of welding girders to the reversal chamber top

Figure 29 — Typical methods of welding girder stays to reversal chambers



a) Distance between manhole reinforcing ring, furnace and shell



b) Distance between manhole reinforcing ring, furnace, tube nest and shell

Key

e_{cp} calculated wall thickness of reinforcing pad

NOTE Figure shows only a design where man hole is considered as a support (see Table 4).

Figure 30 — Distances from manhole reinforcing ring

10.2.6 Stays for wet back reversal chambers

The stays shall comply with the requirements of Formula (53) (also see Figure 31):

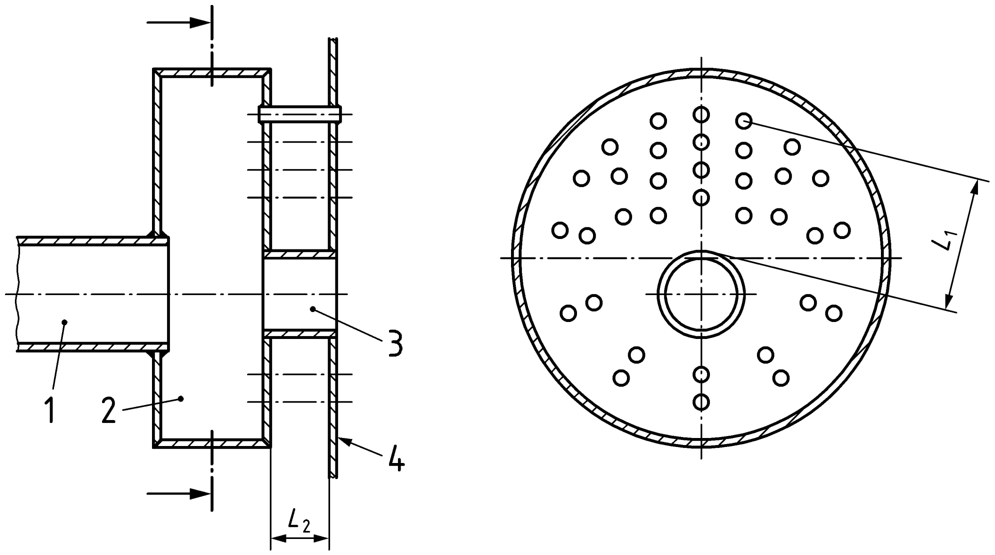
$$\frac{d_s \; L_1}{L_2^2} \leq 2 \qquad (53)$$

where

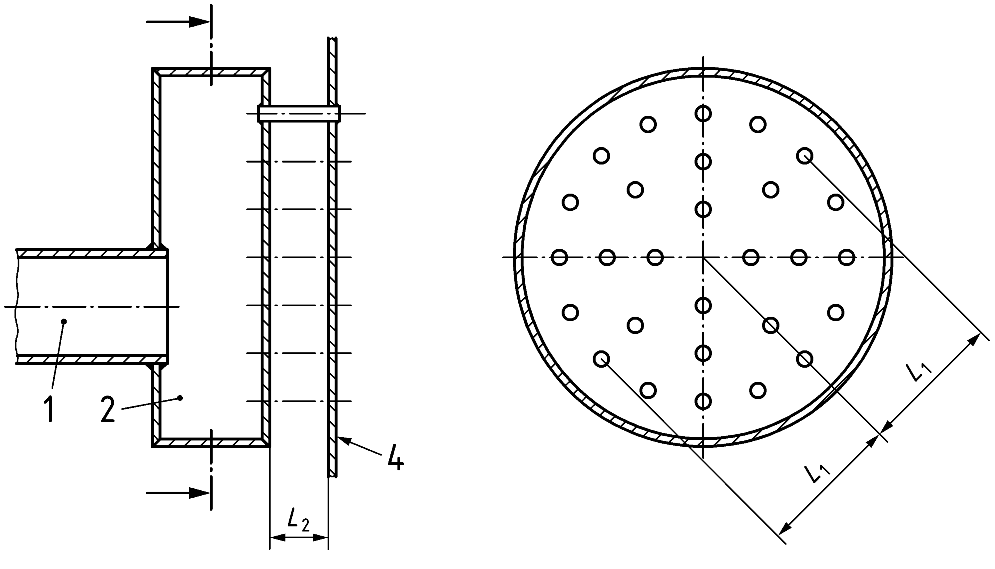
d_s is the diameter of the stay (in mm)

L_1 is the shortest distance from the edge of the access opening to the centre line of the stay furthest away from the access opening (in mm) or where there is no access opening half the maximum distance between centre lines of stays

L_2 is the distance between the rear plate of the chamber and the boiler back endplate (in mm). When the stay bars are attached to the rear plate by fillet weld the dimension L_2 shall be taken to the outside surface of the rear plate.



a) With access opening



b) Without access opening

Key

L_1	shortest distance from the edge of the access opening to the centre-line of the stay furthest away from the access opening, or, where is no access opening, half the maximum distance between the centre-lines of the stays
L_2	distance between the rear plate of the reversal chamber and the boiler back end plate
1	furnace
2	reversal chamber
3	access opening
4	end plate

Figure 31 — Location of stays in reversal chamber back plates

10.2.7 Stay tubes and bars

The permissible stress in the stay (solid or otherwise), calculated on the cross sectional area, shall not exceed the allowable stress for the material of stay at operation condition calculated with $f = R_{p0,2tc}/2$ where $R_{p\,0,2tc}$ is the minimum value between connecting plate and the stay. The diameter of any stay at any part shall be not less than 25 mm with the exception that stays fitted to wet back reversal chambers shall be not less than 20 mm.

The stays may be welded as indicated in Figure 24 to 27.

10.2.8 Loads on stay tubes and bar stays

Stay tubes and bar stays shall be designed to carry the whole load due to the pressure on the area to be supported, the area being calculated as:

a) For a stay tube within the tube nest, the net area to be supported shall be the product of the horizontal and vertical pitches of the stay tubes less the area of the tube holes embraced. Where the pitch of the stay tubes is irregular, the area shall be taken as the square of the mean pitch of the stay tubes (i.e. the square of one-quarter of the sum of the four sides of any quadrilateral bounded by four adjacent stay tubes) less the area of the tube holes embraced.

b) For a stay tube in the boundary row, or for a bar stay, the area to be supported shall be the area enclosed by a line through the midpoints of the lines joining the stay and the adjacent point of support, less the area of any tubes or stays embraced as shown in Figure 23.

c) For a bar stay where there are no stay tubes in the tube nest, the area to be supported shall extend to the tangential boundary of the tube nest.

10.2.9 Gusset stays

10.2.9.1 Principals for staying

The supporting of flat ends using too few gusset stays could lead to unacceptable local deformation of the shell. Therefore, the total load shall be divided into a larger number of gusset stays. The segmental shaped areas of unflanged plates within the free upper space (e.g. the steam space in case of steam boilers) shall be supported by at least two gusset stays.

10.2.9.2 Load on each stay

Each gusset stay supporting the flat end plate of a boiler shall be designed to carry the whole load due to the pressure on the area it supports. The area supported by any one stay shall be obtained by considering the total area to be supported and dividing this area by boundary lines drawn between the stays and the adjacent points of support (furnace, boundary rows of tube nests or the shell). These boundary lines shall be at all points equidistant from the adjacent points of support in the area under consideration (see Figure 23).

10.2.9.3 Calculation of gusset stays

Gusset stays shall be so proportioned that the angle V (see Figure 32) shall be not less than 60°. The minimum cross-section of the gusset shall be determined in accordance with the Formula (54):

$$e_g\, h = \frac{f_G\, W}{f \sin V} \qquad (54)$$

where

$0{,}5 \times$ shell thickness $\le e_g \le 1{,}5 \times$ shell thickness

and

$e_g \ge 0{,}5 \times$ end plate thickness

The values for f_G are:

1,0 for plain furnace.

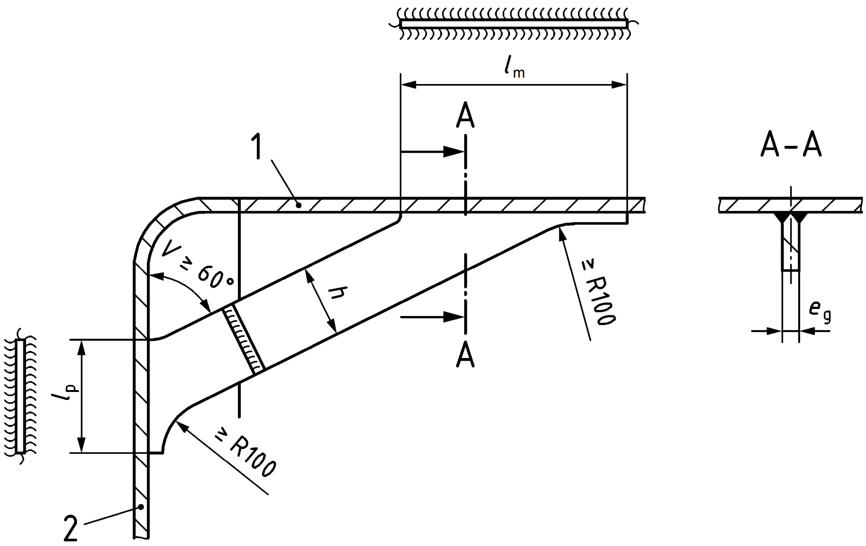
1,0 for corrugated furnace which is separated from the gusset stays e.g. by a tube nest.

1,2 for corrugated furnace according to this standard which is located near to the gusset stay.

However, the required minimum thickness of the gusset stay shall not exceed the shell thickness.

The size and shape of the parts of the end plate supported by each gusset shall be such that the entire surface area of the end plate in each gusset stay zone is supported.

Dimensions in millimetres



Key

e_g calculated thickness of gusset stay

h width of the gusset stay

l_m connection length to the shell

l_p connection length to the end plate

R radius

V angle between gusset stay and end plate

1 shell

2 end plate

Figure 32 — Details of welded gusset stays

l_m and l_p shall meet the requirements of Formulae (55) and (56):

$$l_m \geq \frac{h}{\cos V} + 70mm \quad (55)$$

$$l_p \geq \frac{h}{\sin V} + 50mm \quad (56)$$

The allowable distance of the centre lines between two gussets stays l_a of Figure 23 shall meet the requirements of Formula (57):

$$l_a \leq 1{,}41 \cdot e_h \cdot \sqrt{\frac{400 N/mm^2}{f_G \cdot PS}} \quad (57)$$

NOTE 400 N/mm^2 is the allowable stress of the magnetite protection layer.

10.2.10 Weld attachments

Where gusset stays are welded to the shell and end plates, the attachment shall be by means of full penetration welds in accordance with Figure 32.

The weld profile shall be free from notches and abrupt changes of contour

10.2.11 Additional requirements for set-in end plates

10.2.11.1 General

In addition to the applicable requirements, especially in respect of acceptable weld details (see EN 12953-4), and to the general requirements for flat end plates given in 10.2.3 to 10.2.9, the requirements for welded-on or welded-in set-in end plates given in 10.2.11.2 and 10.2.11.3 shall be taken into consideration.

10.2.11.2 Shell thickness local to the corner joint

For the determination of the shell thickness local to the T-butt weld, equations corresponding to Formulae (16) and (17) shall be used:

$$e_{s'} = e_{cs} + c_2 \tag{58}$$

$$e_{cs} = \frac{p_c\, d_{os}}{2\, f_s\, x + p_c} \tag{59}$$

The stress reduction factor x in Formula (59) depends on the ratio of the end plate to shell thickness, and shall be:

$e_{ch}/e_{cs} \geq 1{,}4 \qquad x = 0{,}85$ (60)

$1 < e_{ch}/e_{cs} < 1{,}4 \qquad x = 1 - 0{,}15 * (e_{ch}/e_{cs} - 1) / 0{,}4$ (61)

$e_{ch}/e_{cs} \leq 1 \qquad x = 1$ (62)

If the shell thickness e_{cs} is calculated in accordance with Formula (17) with a weld factor $v \leq 0{,}85$ the stress reduction factor x need not to be considered.

10.2.11.3 Design parameters

Set-in end plates shall comply with the parameters given in Table 5, and with the following:

a) The wall thickness of the shell shall be calculated in accordance with Formulae (58) and (59), including the stress reduction factor x (see Formulae (60), (61) and (62));

b) The actual wall thickness of the end plate shall not exceed 30 mm;

c) Shell to end plate, furnace to end plate and reversal chamber end plate to wrapper plate seams shall be completely back welded, except in the case of small boilers as permitted in accordance with Table 6.

Table 5 — Design parameters for set-in end plates

Outside diameter of the shell d_{OS} mm		Length between boiler end plates[a] L_b mm		Maximum allowable pressure N/mm²	Ratio of thickness of end plate and shell e_h / e_s
d_{OS} ≤	1 250	L_b ≤	2 750	≤ 2,5	≤ 2,00
				≤ 3,0	≤ 1,55
d_{OS} ≤	1 500	L_b ≤	3 300	≤ 1,6	≤ 2,00
				≤ 2,5	≤ 1,80
				≤ 3,0	≤ 1,35
d_{OS} ≤	1 750	L_b ≤	3 850	≤ 1,0	≤ 2,00
				≤ 1,6	≤ 1,85
				≤ 2,5	≤ 1,60
				≤ 3,0	≤ 1,15
d_{OS} ≤	2 000	L_b ≤	4 400	≤ 1,0	≤ 2,00
				≤ 1,6	≤ 1,65
				≤ 2,5	≤ 1,35
				≤ 3,0	≤ 1,00
d_{OS} ≤	2 500	L_b ≤	5 500	≤ 1,0	≤ 2,00
				≤ 1,6	≤ 1,45
				≤ 2,5	≤ 1,15
d_{OS} ≤	3 000	L_b ≤	6 600	≤ 1,0	≤ 1,65
				≤ 1,6	≤ 1,25
				≤ 2,5	≤ 1,00
d_{OS} ≤	3 500	L_b ≤	7 700	≤ 1,0	≤ 1,40
				≤ 1,6	≤ 1,05
d_{OS} ≤	4 000	L_b ≤	8 800	≤ 1,0	≤ 1,15
If the ratio of thickness of end plate and shell exceeds the values above, a calculation of strength and deformation shall be performed, for example finite element method.					
[a] The 8 800 mm limitation for the length does not apply to tubular heat recovery boiler.					
NOTE 1 It is recommended to use material up to P295GH only. NOTE 2 For material P355GH and/or set-in end plates exceeding the limits mentioned in Table 5 additional load cycles calculations need to be provided.					

Table 6 — Conditions for omitting sections of fillet welds (back welds) from corner joints of flat end plates

Unwelded length mm	Boiler length between end plates L_b mm	Outside diameter of shell d_0 mm	Minimum breathing space between furnace and shell mm	End plate thickness e_{rh} mm	Ratio of end plate to furnace wall thickness e_{rh}/e_{rf}	General requirements for welded factions
≤ 250	≤ 3 000	≤ 1 400	6,5 % of d_0 or 65 mm, whichever is the greater	≤ 20	≥ 1,4	The weld shows full penetration [a].
> 250	≤ 2 500	≤ 1 000	≥ 65	≤ 15		Thorough inspection of the weld is possible. The weld is not heated directly.
[b]	≤ 2 000	≤ 1 200	≥ 80	≤ 20		

For LPB the fillet welds (back welds) may be omitted.

[a] To be proved by special procedure tests. The procedure test piece shall reproduce the geometry of the production weld and shall be sectioned for visual and macro examination.

[b] One length equal to the furnace diameter for the flat end to furnace connection and one length equal to the shell diameter for the flat end to shell connection.

10.2.12 Girder stays supporting the flat section of a reversal chamber

The thickness of welded-on girders e in accordance with Figures 29 a) to 29 e) shall be calculated in accordance with Formula (63), but in no case shall the thickness exceed 35 mm:

$$e = \frac{3\, p_c\, L_g^2\, P_g}{4\, d_g^2\, f} \tag{63}$$

11 Design of isolated openings in boiler flat end plates

11.1 Unreinforced isolated openings

The maximum diameter of an unreinforced opening in a flat end plate shall be determined from the Formula (64):

$$d_{max} = 8\, e_{rh} \left(1{,}5 \frac{e_{rh}^2}{e_{ch}^2} - 1 \right) \tag{64}$$

11.2 Branch openings

Reinforcement of branch openings shall be achieved by taking account of locally disposed material, including the attachment welds, in excess of the minimum requirements for end plate and branch thickness as shown in Figure 33. The branch thickness shall be increased where required. Compensation shall be considered adequate when the compensating area Y is equal to or greater than the area X requiring compensation.

Area X shall be obtained by multiplying 25 % of the inside radius of the branch by the thickness of the flat end plate, calculated from Formula (52) for the part of the end plate under consideration.

Area Y shall be measured in a plane through the axis of the branch parallel to the surface of the flat end plate, and shall be calculated:

a) For that part of the branch which projects outside the boiler, calculate the full sectional area of the branch up to a distance l_b from the actual outer surface of the flat end plate and deduct from it the sectional area that the branch would have within the same distance if its thickness were calculated in accordance with Formulae (16) and (17) taking $v = 1$;

b) Add to it the full sectional area of that part of the branch that projects inside the boiler (if any) up to a distance l_b from the inside surface of the flat end plate;

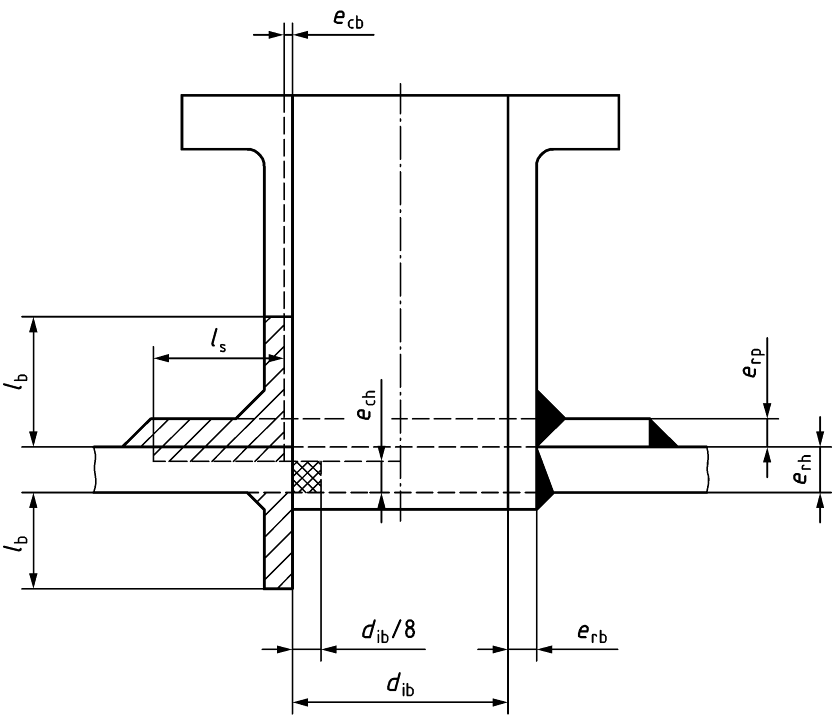
c) Add to it the sectional area of the fillet welds;

d) Add to it the area obtained by multiplying the difference between the actual flat end plate thickness and its thickness calculated from Formula (52) for the part of the end plate under consideration by the length l_s ;

e) Add to it the area of the compensating plate (if any) within the limits of reinforcement shown in Figure 33.

Where material having a lower allowable stress than that of the flat end plate is taken as compensation, its effective area shall be reduced in the ratio of the allowable stresses at the calculation temperature. No credit shall be taken for the additional strength of material having a higher allowable stress than that of the flat end plate.

Welds attaching branches and compensating plates shall be capable of transmitting the full strength of the reinforcing area and all other loadings to which they may be subjected.



Key

d_{ib}	inside diameter of branch
e_{cb}	calculated wall thickness of branch calculated in accordance with Formulae (16) or (17) taking v = 1.
e_{ch}	calculated wall thickness of flat end plate in accordance with Formula (52)
e_{rb}	actual wall thickness of branch
e_{rh}	actual wall thickness of flat end plate
e_{rp}	actual wall thickness of reinforcing pad
l_b	smaller of the two values 2,5 e_{rh} and (2,5 e_{rb} + e_{rp}).
L_s	greater of the two values (e_{rh} + 75) and (d_{ib}/2).
Area X	
Area Y	

area Y shall not be less than area X.

NOTE The compensating plate is required only in cases where area Y would otherwise be less than area X.

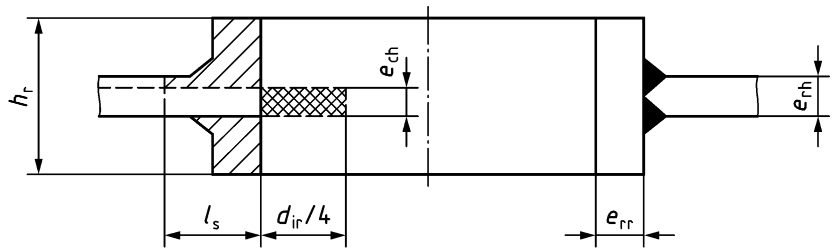
Figure 33 — Compensation of branch in flat end plate

11.3 Manholes, headholes and handholes

When elliptical manholes, headholes or handholes are located in flat end plates, the openings shall be compensated (see Figure 34). The method given in 11.2 for calculating the required area of reinforcement shall be used where applicable except that the thickness of the stiffening ring e_{sr} shall be not less than 19 mm for manholes, 15 mm for headholes and 10 mm for handholes.

Area X shall be obtained by multiplying half the mean of the major and minor semi-axes of the opening by the thickness of the flat end plate, calculated from Formula (52), for the part of the end plate under consideration.

The full thickness of the stiffening ring may be used when calculating area Y.



Key

d_{ir} half the mean of the major and minor semi-axes of the opening / reinforcing ring

e_{ch} calculated wall thickness of flat end plate in accordance with Formula (52)

e_{rh} actual wall thickness of flat end plate

e_{rr} actual wall thickness of reincorcing ring

h_r height of reinforcing ring

l_s greater of the two values (e_{rh} + 75) and d_{ir}.

Area X

Area Y

Area Y shall not be less than area X.

Figure 34 — Compensation for elliptical manholes or inspection openings in flat end plates

12 Unpierced tubes and tube plates

12.1 Thickness of straight tubes subject to external pressure

Wall thickness of straight tubes ≤ 170 mm nominal outside diameter, subjected to external pressure, shall be given by Formula (65) or Table 7, whichever is the larger.

$$e = e_{ct} + c_1 + c_2 \qquad (65)$$

with

$$e_{ct} = \frac{p\, d_o}{1{,}6\, f} \qquad (66)$$

Table 7 — Lowest nominal thickness of tubes

Dimensions in millimetres

Nominal outside diameter	Lowest nominal thickness
$d_0 \leq 26{,}9$	1,90
$26{,}9 < d_0 \leq 54{,}0$	2,20
$54{,}0 < d_0 \leq 76{,}1$	2,50
$76{,}1 < d_0 \leq 88{,}9$	2,80
$88{,}9 < d_0 \leq 114{,}3$	3,15
$114{,}3 < d_0 \leq 139{,}7$	3,50
$139{,}7 < d_0 \leq 168{,}3$	3,99

12.2 Thickness of straight tubes subject to internal pressure

Wall thickness of straight tube subjected to internal pressure shall be given by Formula (67) or Table 7, whichever is the larger:

$$e_{t'} = e_{ct} + c_1 + c_2 \tag{67}$$

where

c_2 = 0,75 mm

$$e_{ct} = \frac{p_c\, d_o}{2\, f + p_c} \tag{68}$$

12.3 Wall thickness and ovality of elbows and tube bends

12.3.1 General

The wall thickness of elbows (see Figure 37), tube bends ≤ 170 mm nominal outside diameter shall be not less than that given by the Formulae (69) and (70):

wall thickness at the intrados

$$e_{ti} = e_{ct}\, C_i + c_1 + c_2 \tag{69}$$

wall thickness at the extrados

$$e_{to} = e_{ct}\, C_o + c_1 + c_2 \tag{70}$$

where e_{ct} is the thickness calculated for a straight tube in accordance with 12.1 or 12.2 as appropriate, and C_i and C_o are factors to be taken from Figure 38 and Formulae (71) and (72).

$$C_i = \frac{\frac{2R}{d_o} - 0{,}5}{\frac{2R}{d_o} - 1} \tag{71}$$

$$C_o = \frac{\frac{2R}{d_o} + 0{,}5}{\frac{2R}{d_o} + 1} \tag{72}$$

where

R is the centre line of the bore of the bend.

The factors C_i and C_o shall be applicable for elbows and tube bends where the ratio R/d_o is greater than or equal to 1 and less than or equal to 4,5. Bends with R/d_o greater than 4,5 shall be treated as straight tubes.

Minimum wall thicknesses shall be taken into account in accordance with 12.1 or 12.2 as appropriate.

The value of the ratio d_m/e shall not exceed 40.

For calculations out of the limits or as an alternative, EN 12952-3:2011, Annex A shall be taken into consideration.

12.3.2 Departure from circularity of the tube bends

The departure from circularity of tube bends shall be calculated from the equation:

$$u = 2 \times \frac{\hat{d}_0 - \breve{d}_0}{\hat{d}_0 + \breve{d}_0} \times 100 \tag{73}$$

where

u is the departure from circularity, in %;

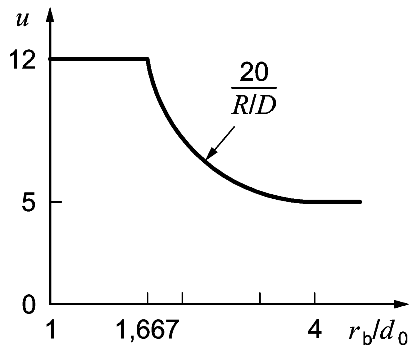
$\widehat{d}_0$ is the maximum outside diameter measured at the tube bend apex, in mm;

$\breve{d}_0$ is the minimum outside diameter measured at the same cross-section as $\widehat{d}_0$, in mm.

The permitted departure from circularity shall be within the limits given in Figures 35 and 36.

a) the departure from circularity of tube bends, which are bent in a single continuous operation, shall not exceed the limits shown in Figure 35;

b) the departure from circularity of tube bends on tubes not exceeding 80 mm nominal outside diameter, which are bent by a double operation i.e. hot pressed after the primary bending operation then post-bend heat treated shall not exceed the limits shown in Figure 36.

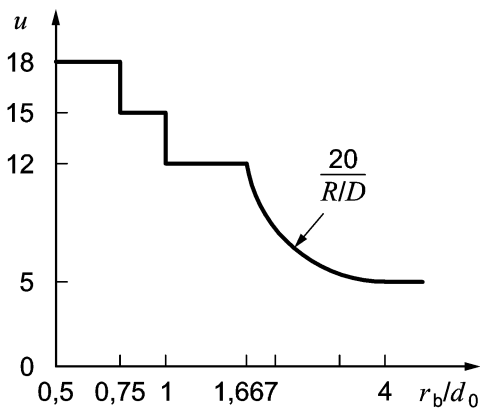


Key

R/D ratio of bending radius to outside diameter

u departure from circularity

Figure 35 — Limits of departure from circularity for single operation bending

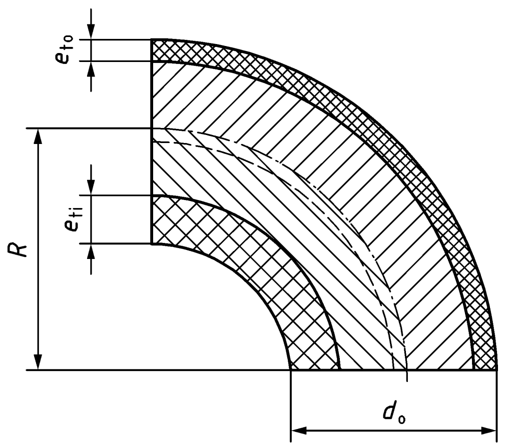


Key

R/D ratio of bending radius to outside diameter

u departure from circularity

Figure 36 — Limits of departure from circularity for double operation bending



Key

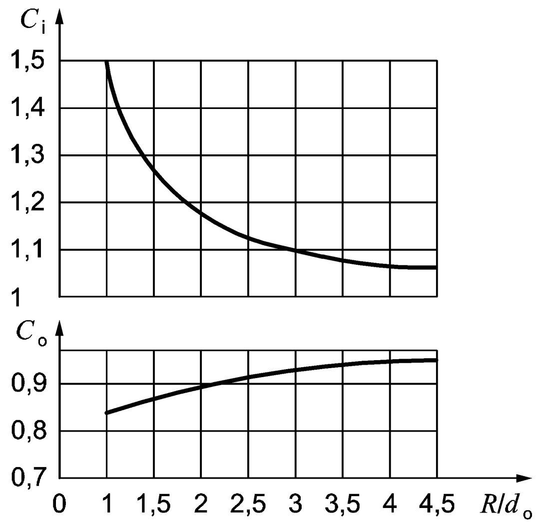
d_o nominal outside diameter

R bending radius

e_{to} extrados tube wall thickness

e_{ti} intrados tube wall thickness

Figure 37 — Notation used for tube bends



Key

d_o nominal outside diameter

R radius

C_i design factor intrados

C_o design factor extrados

Figure 38 — Design factors C_i and C_o

12.4 Smoke tubes

Smoke tubes, which act as stay tubes, shall be connected in accordance with Table 8 having a weld depth, equal to the tube thickness plus 2 mm, or the weld shear cross section shall be equal to or greater than 1,25 multiplied by the required cross sectional tube area, with a minimum weld depth of 2 mm.

Each smoke tube and its connection to tube plates shall be designed to carry its due proportion of the load on the plates which it supports. The thickness of tubes connected to tube plates shall be such that the axial stress on the thinnest part of the tube does not exceed $f = R_{p0,2tc} / 2$

This requirement refers to:

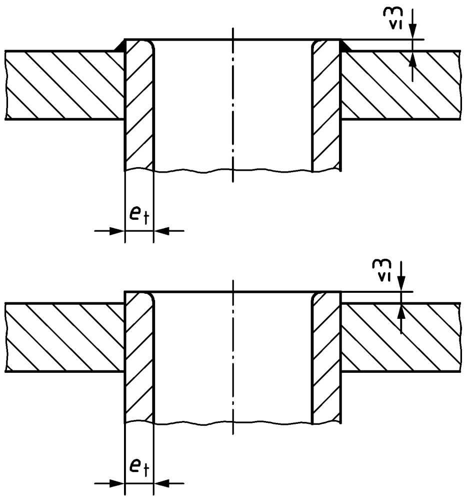
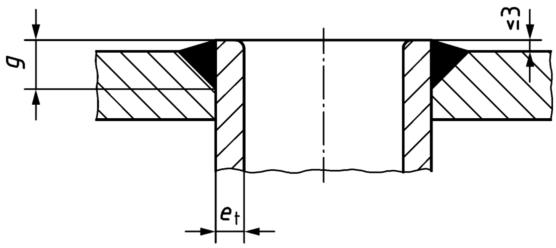
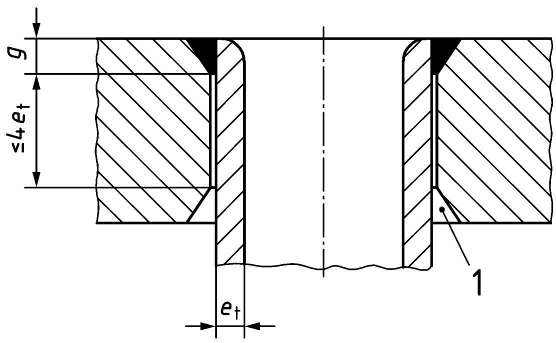
— welded-in smoke tubes of a tube field, that are in an exposed position;

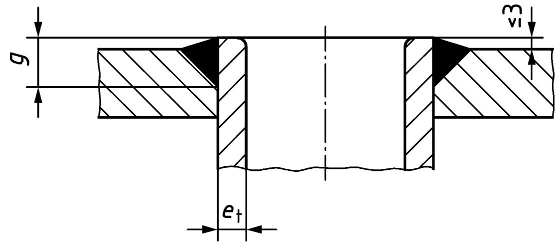
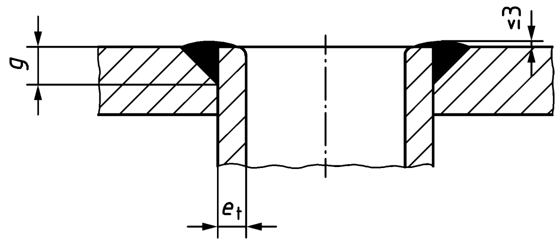
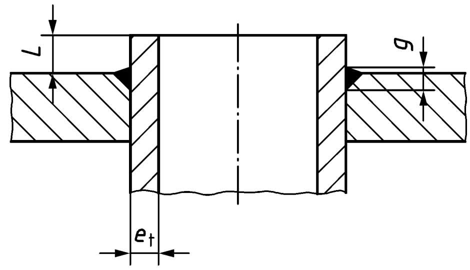
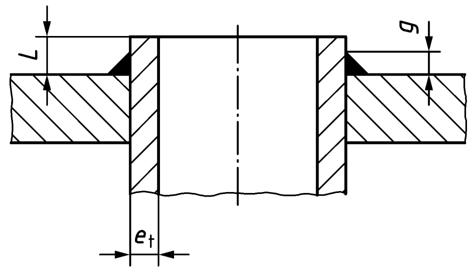
— welded-in smoke tubes that act as a stay tube;

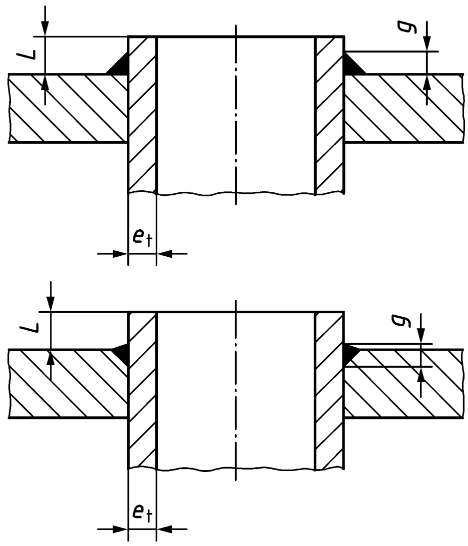
— all expanded tubes.

At gas entry temperatures of more than 900 °C, the inner edge of the smoke tubes shall be rounded or bevelled.

Table 8 — Permitted methods of attaching smoke tubes

N° of Figure Connecting type	Figures	Temperature Conditions	Geometric conditions
a Fully expanded with or without sealing weld			If expanded tubes are to be designed as load-carrying (stay tubes), the strength of the expanded joint shall be determined by process qualification. In this case, the expansion is designed to carry the axial load of the tube.
b Expanded and welded			$g \geq 1,25\ e_t$ Ends of the tubes shall be flush with the weld In this case, the expansion is made to ensure full contact between the tube and the tube plate. For smoke tubes, which act as stay tubes, it is permissible to increase the weld groove depth beyond 2 mm in order to satisfy the welding requirements in 12.4.
c Welded with cooling groove or welded and expanded with cooling groove			Ends of the tubes shall be flush with the weld Stick-out of tube and weld 3 mm max. beyond tube plate $g \geq 1,25\ e_t$

N° of Figure **Connecting type**	**Figures**	**Tempera-ture Condi-tions**	**Geometric condi-tions**
d Welded or expanded and welded	 		Ends of the tubes shall be flush with the weld Stick-out of tube and weld 3 mm max. beyond tube plate $g \geq 1{,}25\ e_t$ $e_h \leq 16$ mm
e Welded	 	T inlet < 600°C or T outlet < 700°C :	$L \leq 18$ mm (≤500°C : $L \leq 25$ mm) $g \geq 1{,}25\ e_t$

N° of Figure Connecting type	Figures	Temperature Conditions	Geometric conditions
f Welded or expanded and welded		T inlet < 600°C	Fully tubed heat recovery boilers generating hot water $g \geq e_t$ $L \leq 18$ mm (≤500°C : $L \leq 25$ mm)
NOTE Weld preparations as well as cooling groove presented within the sketches are only examples. **Key** *g* weld connection length to the smoke tubes *L* tube stick-out e_t wall thickness of the tube			

12.5 Pitch of tubes

The spacing of tube holes shall be such that the minimum width, in millimetres, of any ligament between the tube holes shall be not less than:

a) for expanded tubes,

0,125 *d* + 12,5 mm

b) for welded tubes,

1) for gas entry temperatures greater than 800 °C,

0,125 *d* + 9 mm, but need not exceed 15 mm;

2) for gas entry temperatures less than or equal to 800 °C,

0,125 *d* + 7 mm, but need not exceed 15 mm.

3) for fully tubed heat recovery boilers, generating hot water, with flue gas entry temperatures of not more than 600°C (e.g. heat exchanger behind oil or gas engines):

0,125 *d* + 4 mm, but need not exceed 15 mm

12.6 Thickness of the tube plates within tube nests

The thickness of tube plates shall be calculated from Formulae (51) and (52), but shall be not less than:

a) $e_h \geq 12$ mm where the tubes are expanded into the tube plate when the diameter of the tube hole does not exceed 50 mm, or $e_h \geq 14$ mm when the diameter of the tube hole is greater than 50 mm, or

b) $e_h \geq 6$ mm where the tubes are attached to the tube plate by welding only.

13 Furnaces tubes, furnace components and reversal chambers of cylindrical form subject to external pressure

13.1 Furnaces tubes

13.1.1 Plain furnaces tubes

The calculation pressure of plain furnaces tubes shall be the lower of the calculation pressures obtained using Formulae (74) and (75):

$$p_c = \frac{R_{p\,0,2\,tc}}{S_1} \frac{2\,e_{cf}}{d_m} \frac{1+0,1\,d_m/L}{1+\left(0,03\,d_m/e_{cf}\right)\left[u/\left(1+5\,d_m/L\right)\right]} \tag{74}$$

$$p_c = \frac{2,6\,E}{S_2\,L}\left(\frac{e_{cf}}{d_m}\right)^2 \sqrt{d_m\,e_{cf}} \tag{75}$$

The preceding equations may be expressed in terms of thickness as shown in Formulae (76) and (78). The greater of the thicknesses obtained shall be used, but the thickness e_{fa} of plain furnaces with diameters less than or equal to 400 mm shall be not less than 6 mm, and for diameters greater than 400 mm, shall be not less than 7 mm. Bowling hoop furnaces shall have a thickness e_{fa} of not less than 10 mm. In no case shall the thickness e_{fa} exceed 22 mm, see EN 12953-4:2002, 5.9.3.

$$e_{cf} = \frac{B}{2}\left[1+\sqrt{1+\frac{0,12\,d_m\,u}{\left(1+5\,d_m/L\right)B}}\right] \tag{76}$$

where

$$B = \frac{p_c\,d_m\,S_1}{2\,R_{p\,0,2\,tc}\left(1+0,1\,d_m/L\right)} \tag{77}$$

$$e_{cf} = d_m^{0,6}\left[\left(L\,S_2\,p_c\right)/\left(2,6\,E\right)\right]^{0,4} \tag{78}$$

$$e_{fa} = e_{cf} + c_1 + c_2 \tag{79}$$

where

c_2 = 0,75 mm (corrosion allowance)

S_1 and S_2 are safety factors (see 13.1.3).

Formulae (74) to (79) shall apply to furnaces tubes having diameters ≤ 1 800 mm (see 5.5.2).

NOTE Formulae (74) and (76) are based on considerations of plastic deformation. Formulae (75) and (78) are based on considerations of elastic instability.

13.1.2 Corrugated furnaces tubes

The calculation pressure of corrugated furnaces tubes shall be determined using Formula (80), but the thickness e_{fa} shall be not less than 10 mm not greater than 22 mm, see EN 12953-4:2002, 5.9.3:

$$p_c = \frac{R_{p\,0,2\,tc}}{S_1} \frac{2\,X_2}{P_{cor}\,d_m} \frac{1+0,1\,d_m/L}{1+\left[\frac{X_2\,w\,d_m}{800\,I_1}\frac{u}{1+\left(5\,d_m/L\right)\left(e_{cf}/w\right)^3}\right]} \tag{80}$$

where

d_m is the mean diameter.

NOTE 1 For corrugated furnace tubes, the mean diameter is equal to the inside diameter plus the full depth of one corrugation, i.e. inside diameter plus w (see Figure 39).

NOTE 2 Values of X_2 and I_1 for Fox corrugations are given in Tables 9 and 10.

13.1.3 Safety factors

Values for safety factors in operating condition shall be:

$S_1 = 2,5$ for furnaces tubes and wrapper plates exposed to flame with $p_c > 0,6$ MPa or;$p_c \leq 0,6$ MPa and $d_m/L < 0,25$

$S_1 = 2,0$ for furnaces tubes and wrapper plates exposed to flame with $p_c \leq 0,6$ MPa and $d_m/L \geq 0,25$;

$S_1 = 2,0$ for furnaces tubes and wrapper plates not exposed to flame;

$S_2 = 3,0$ for calculation condition;

Values for safety factors in test condition shall be:

$S_{t1} = 1,4$ for all furnaces tubes and wrapper plates;

$S_{t2} = 2,2$ for all furnaces tubes and wrapper plates.

13.1.4 Furnace components

The thickness of the furnace components e.g. ash drop tubes and fuel inlet connections, shall be calculated in accordance with 13.1.1 with a minimum thickness of 10 mm and a maximum thickness of 22 mm, see EN 12953-4:2002, 5.9.3.

Compensation for openings in furnaces tubes shall be provided in accordance with 8.3, except that the use of reinforcing pads shall not be permitted.

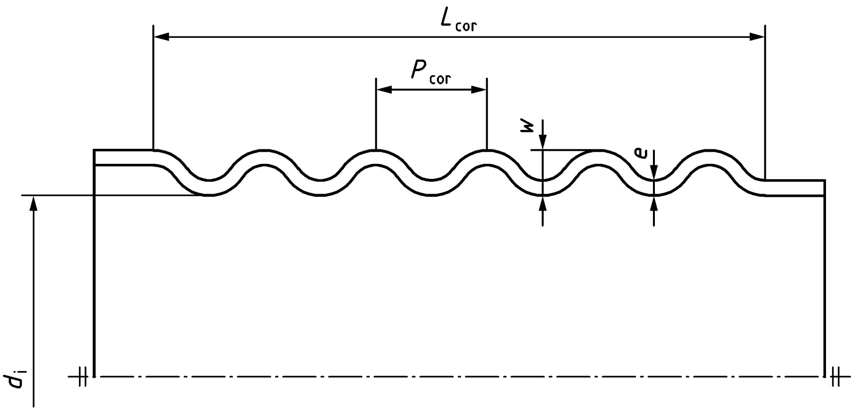
The thickness of access tubes shall be calculated in accordance with 13.1.1 with a minimum thickness of 10 mm.

13.1.5 Reversal chambers

The thickness of wrapper plates of cylindrical reversal chambers shall be calculated in accordance with the equations given in 13.1.1. Where non-circular geometry is employed using plates of different radii, the thickness shall be calculated using the maximum radius.

Where the use of reversed curvature sections is involved, a check shall be made that the sections may sustain the maximum allowable pressure without the design stress being exceeded and, if necessary, the thickness appropriately increased. A suggested method is given in Annex A.

The thickness shall be not less than 10 mm and not greater than 35 mm. If the reversal chamber is complete circular and without any stiffeners, the minimum thicknesses of 13.1.1 can be used.



Key

d_i inside diameter

e wall thickness

L_{cor} total length of corrugation

P_{cor} pitch of corrugations

w nominal overall depth of corrugation

Figure 39 — Cross sectional area for Fox type corrugated tube

Table 9 — Second moments of area for Fox type corrugated tube (150 corrugation and 50 overall depth) (mm)

Wall thickness without corrosion allowances	Second moment of area	Cross sectional area
$e_{rf} - c$ mm	I_1 10^4 mm^4	X_2 10^2 mm^2
9,25	35,6	16,4
10,25	37,7	18,0
11,25	39,6	19,6
12,25	41,2	21,2
13,25	42,7	22,8
14,25	44,1	24,4
15,25	45,3	25,9
16,25	46,4	27,4
17,25	47,4	28,9
18,25	48,3	30,4
19,25	49,2	31,9
20,25	50,1	33,3
21,25	51,0	34,8

Table 10 — Second moments of area for Fox type corrugated tube (200 corrugation and 75 overall depth) (mm)

Wall thickness without corrosion allowances	Second moment of area	Cross sectional area
$e_{rf} - c$ mm	I_1 10^4 mm^4	X_2 10^2 mm^2
9,25	129,4	23,3
10,25	138,9	25,7
11,25	147,7	28,0
12,25	155,9	30,4
13,25	163,5	32,6
14,25	170,5	34,9
15,25	177,0	37,1
16,25	183,0	39,4
17,25	188,5	41,5
18,25	193,6	43,7
19,25	198,4	45,8
20,25	202,8	48,0
21,25	206,9	50,0

13.2 Calculation length of composite furnaces tubes

When the length of the plain portion of a corrugated tube exceeds 250 mm, the total length of both sections shall be used for calculating the thickness of the corrugated section, and 1,5 times the length of the plain section shall be used for calculating the thickness of the plain section.

13.3 Tolerances of furnaces tubes

For corrugated furnaces tubes, the calculated wall thickness shall be the minimum thickness of the finished furnaces tubes.

The departure from circularity u of furnaces tubes and reversal chambers shall be calculated using Formula (81):

$$u = \frac{2\left(\hat{d} - \breve{d}\right)}{\hat{d} + \breve{d}} \times 100 \quad (81)$$

where

$\hat{d}$ is the maximum mean diameter of the furnace;

$\breve{d}$ is the minimum mean diameter of the furnace.

For tolerances of furnaces tubes, see EN 12953-4.

The value of u in Formulae (74), (76) and (80) shall be taken as 1 % for corrugated furnaces tubes and 1,5 % for plain furnaces tubes.

13.4 Stiffeners

13.4.1 General

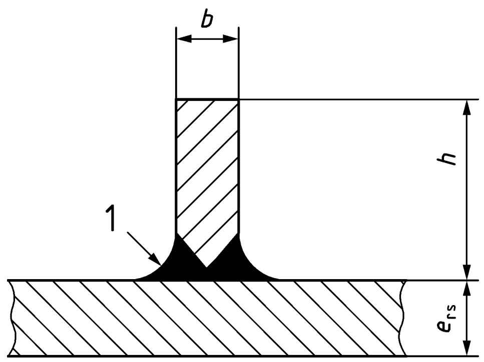
Stiffeners welded to furnaces tubes shall be regarded as fulfilling the requirements of this section and need not be calculated, provided $2\ e \leq b$ and $5\ e \leq h \leq 6\ b$ as per Figures 40 and 41.

Stiffeners not conforming to Figures 40 and 41 shall have a second moment of area not less than that given by Formula (82):

$$I_2 = \frac{p_c\, d_m^3\, L}{1{,}33 \times 10^6} \quad (82)$$

The second moment of area of the stiffener about its neutral axis I_2 shall be related to the stiffener section, including a length of furnace equal to $0{,}55\sqrt{d_m\, e_{cf}}$ on either side of the stiffener.

Dimensions in millimetres



Key

b thickness of the stiffener

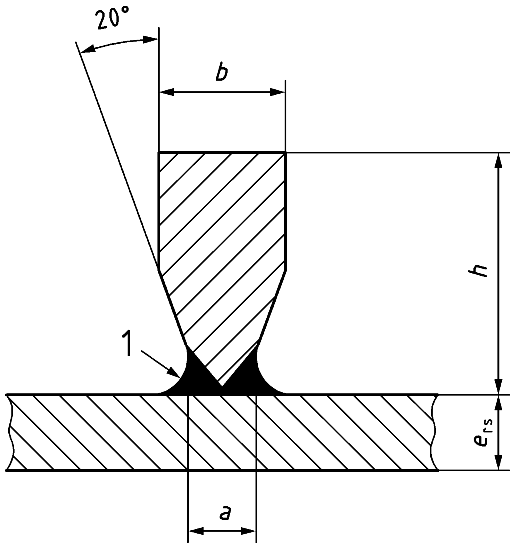
e wall thickness

h height of the stiffener

1 continuous full penetration weld

Figure 40 — Furnace stiffeners up to and including 22 mm thick for plain and corrugated sections

Dimensions in millimetres



Key

a wall thickness of the stiffener at the connection point ≤ 22 mm

b thickness of the stiffener

e_{rs} wall thickness

h height of the stiffener

1 continuous full penetration weld

Figure 41 — Furnace stiffeners thicker than 22 mm for plain and corrugated sections

13.4.2 Stiffener sections made from bar or plate

Stiffener sections made from bar or plate shall be joined by full penetration welds.

The thickness of the stiffening ring shall be kept to the minimum required by 13.4.1. If it exceeds 22 mm, or twice the furnace thickness, it shall be tapered as shown in Figure 41.

Stiffening rings need not be manufactured from the same material as the furnace but shall have the same modulus of elasticity and coefficient of linear expansion as the furnace material. The stiffening ring materials shall be selected from those materials specified in EN 12953-2:2012.

Full penetration welds shall be used to attach stiffeners to furnaces tubes.

13.4.3 Stiffeners located within the zone of peak heat flux

When stiffeners are welded on to furnaces tubes which are more than 11 mm thick they shall not be located in the zone of peak heat flux. The zone of peak heat flux shall be considered to extend for a length equal to two times the minimum required furnace diameters according to 5.5, from the tip of the burner, or to the end of the grate, whichever is applicable.

NOTE The requirements of 13.4.3 need not apply to boilers with a heat input less than 2 MW.

13.4.4 Bowling hoops

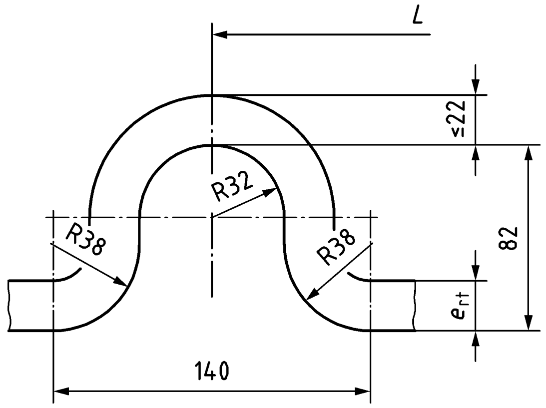
Bowling hoops shall be considered effective points of support. The minimum pitch of bowling hoop centres and the distance between bowling hoop and a fixed point of support shall be taken, for calculation purposes, as one third of the inside diameter of the furnace, but not less than 500 mm. When bowling hoops are used, the furnace thickness shall be calculated in accordance with 13.1.1.

In the calculation for furnaces tubes supported by bowling hoops, in Clause 13.1.1 *L* shall be taken as 1,5 times the actual length between bowling hoop centres.

The second moment of area of bowling hoops is given in the tables to Figures 42 a) to c). The second moment of area of the bowling hoop shall be greater or equal as calculated by Formula (82), L shall be taken as the actual length between bowling hoops.

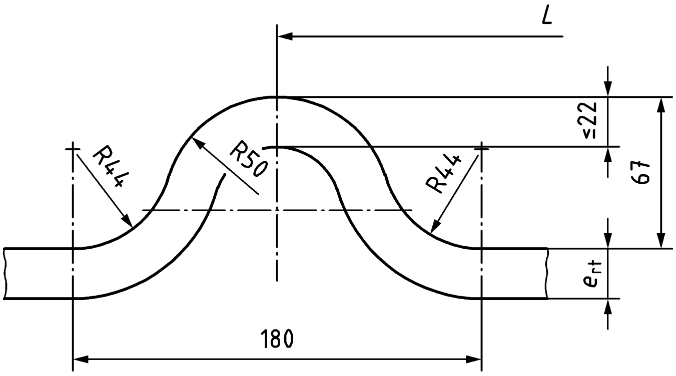
The nominal wall thickness of bowling hoops shall not be less than the nominal wall thickness of the plain furnaces tubes to which they are attached.

Dimensions in millimetres



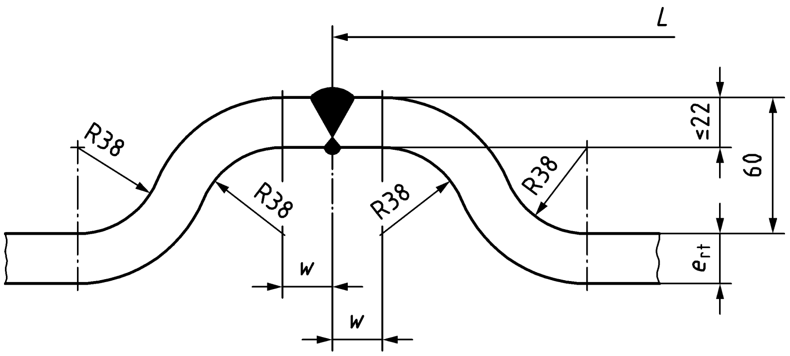
a)

Wall thickness without corrosion allowances	Second moment of area
$e_{rt} - c$	I_2
mm	10^6 mm^4
9,25	1,90
10,25	2,11
11,25	2,32
12,25	2,53
13,25	2,74
14,25	2,96
15,25	3,18
16,25	3,40
17,25	3,62
18,25	3,85
19,25	4,08
20,25	4,31
21,25	4,55



b)

9,25	1,30
10,25	1,44
11,25	1,59
12,25	1,74
13,25	1,90
14,25	2,04
15,25	2,20
16,25	2,36
17,25	2,52
18,25	2,68
19,25	2,84
20,25	3,01
21,25	3,18



9,25	1,14
10,25	1,28
11,25	1,41
12,25	1,55
13,25	1,70
14,25	1,86
15,25	2,04
16,25	2,22
17,25	2,41
18,25	2,60
19,25	2,80
20,25	3,01
21,25	3,22

c)

Key

e_{rt} actual tube wall thickness without allowances

L distance between two effective points of furnace support

w nominal overall depth of corrugation

NOTE $W = e_{rt} - c$, but not less than 13.

Figure 42 — Bowling hoops

14 Access and inspection openings

14.1 General requirements

14.1.1 All boilers shall be provided with openings adequate in size and number to allow sufficient access for fabrication, cleaning and internal inspection. The dimensions of the openings shall be in accordance with 14.2.

14.1.2 Boilers with a shell diameter:

a) $d_o \geq 1\,400$ mm shall be designed to permit entry of a person and shall be provided with a manhole for this
purpose.

b) d_o between 1 400 mm and 800 mm shall be provided with a headhole as a minimum requirement.

c) $d_o < 800$ mm, are allowed to be designed with alternative means to perform internal inspections. The means can be in a form of openings (head hole, access through flanged connections, disassembling pipes from nozzles etc.), where the use of remote visual inspection techniques, e.g. endoscope, can be used.

14.1.3 For certain boilers where the internal spaces are completely filled by the heating surfaces (e.g. smoke tubes, such as hot water boilers, it is permissible to fit alternative types of inspection openings to provide access to the upper areas of the boiler. This can include the provision of pads with blind flanges or by dismantling pipework at nozzle connections. Remote visual inspection (RVI) equipment can also be used where appropriate. The number and size of alternative inspection openings shall be sufficient to provide adequate visual access to the upper internal surfaces of the boiler.

14.1.4 The number, size and location of access and inspection openings shall vary according to the boiler design to ensure that a good representative visual examination of the welded seams is possible.

14.2 Types and minimum dimensions of access and inspection openings

The shape of inspection openings can be either circular or oval.

a) Handholes (see Figure 43 d))

A handhole for cleaning shall be not less than 80 mm × 100 mm or shall have an inside diameter of 100 mm.

A handhole for inspection shall be not less than 100 mm × 150 mm or shall have an inside diameter of 120 mm. The height of the neck or ring h_t shall not exceed 65 mm, or 100 mm if the neck or ring is conical.

b) Headholes (see Figure 43 c))

Headholes shall be not less than 220 mm × 320 mm or shall have an inside diameter of 320 mm. The height of the neck or ring h_t shall not exceed 100 mm, or 120 mm if the neck or ring is conical.

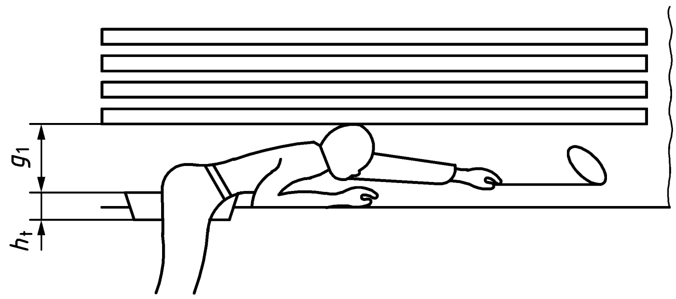
c) Manholes (see Figures 43 a), b), e))

Manholes shall be not less than 320 mm × 420 mm or shall have an inside diameter of 420 mm. The height of the neck or ring h_t shall not exceed 300 mm.

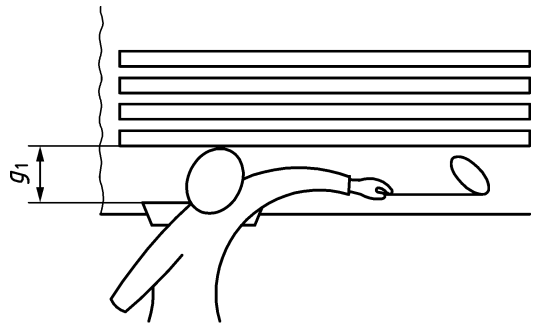
d) Nozzle for remote visual inspection (RVI)

Nozzle used for remote visual inspection shall not be less than DN 50.

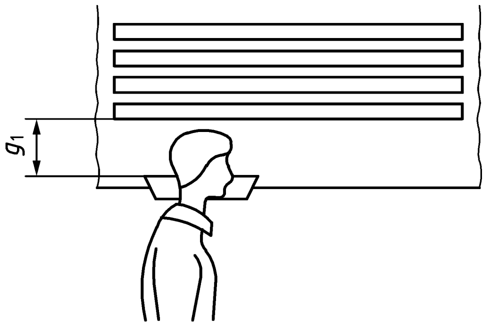
Dimensions in millimetres



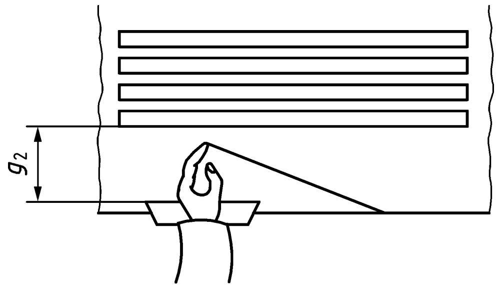
a)



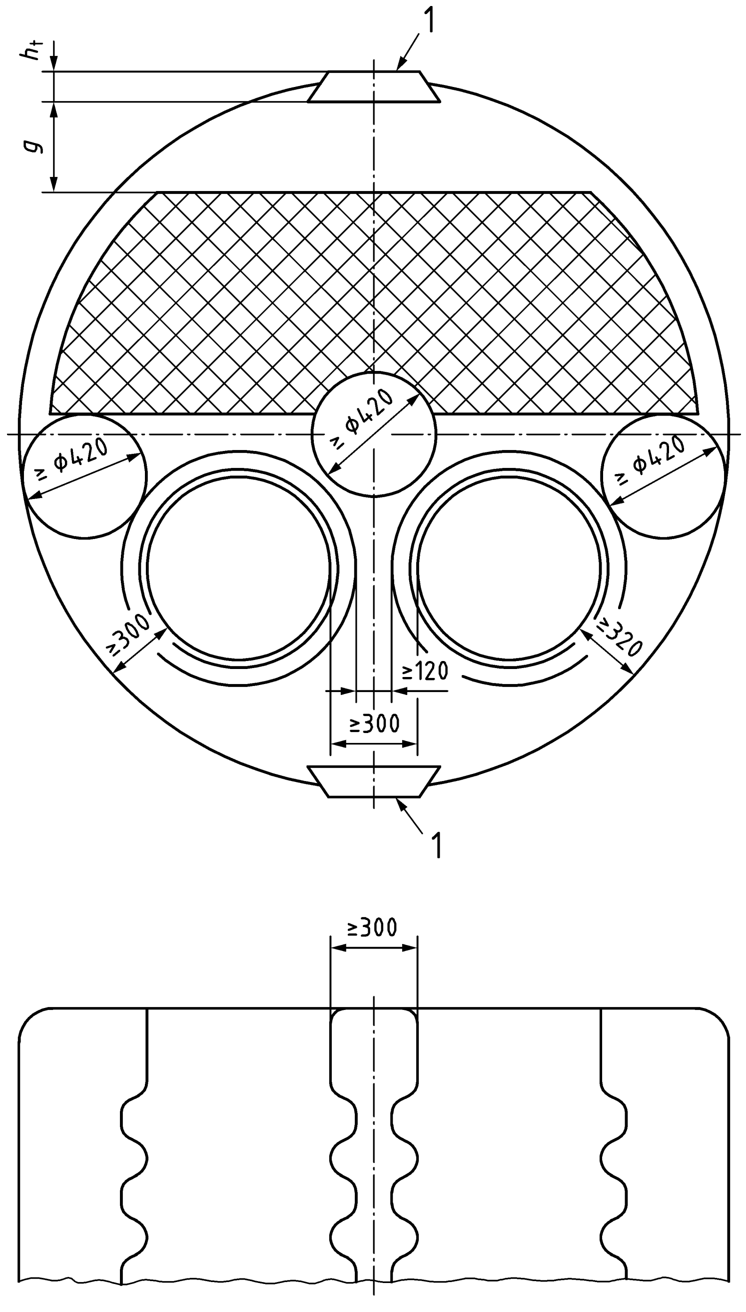
b)



c)



d)



e)

Key

g, g_1, g_2 clear height

h_t height of the opening ring

1 manhole

NOTE 1 Dimensions and distances for openings for access and inspection h_t, g_1 and g_2, see Table 11.

NOTE 2 h_t is applicable for Figures 43 a), b), c) and d).

NOTE 3 For the size of manhole and dimension *g*, see Table 11.

NOTE 4 subfigure e) shows an example according to 14.5.2.

Figure 43 — Openings for access and inspection

Table 11 — Openings for access and inspection

Type	h_t	g	g_1	g_2	Figures
Manhole 320 × 420 (mm)	300	400	320	—	43 a) e)
Head hole (mm)	100	—	150	—	43 c)
Hand hole (mm)	65	—	—	150	43 d)
Nozzle for remote visual inspection (RVI)	—	—	—	—	—

g ≥ required distance between lower edge of opening ring and boiler internals to allow human access.

$g1$ ≥ required distance between lower edge of opening ring and boiler internals to allow access with head using manholes or headholes.

$g2$ ≥ required distance between lower edge of opening ring and boiler internals for use as a handhole (i.e. inspection with mirror).

h_t ≤ height of the opening ring.

NOTE For further requirements, see 14.5.

14.3 Minimum gasket bearing width and clearance for access and inspection doors

Access and inspection doors of the type in which the internal pressure forces the door against a flat gasket shall have a minimum gasket bearing width of 15 mm for manholes and headholes. For handholes, the gasket bearing width may be reduced to 10 mm. The total clearance between the door frame and the spigot or recess of such doors shall not exceed 3 mm, i.e. 1,5 mm all round, and the spigot depth shall be sufficient to trap the gasket.

14.4 Access and inspection openings in flat plates

Where access and inspection openings are located in flat plates, the openings shall be suitably reinforced (see Figure 34).

14.5 Requirements for entry area into boilers with a shell outside diameter greater than 1 400 mm

14.5.1 The space available in the entry area in the axial directions performed according to EN 13445-3 along the boiler shall include at least one cross-section which is comparable with one measuring 600 mm diameter. This requirement shall be considered satisfied if the space includes an inscribed circle of at least 420 mm diameter and adjacent wedge-shaped spaces which guarantee sufficient freedom of movement. When entering along the bottom of the boiler (or in similar situations of movement, e.g. above tube assemblies), as well as when climbing in through a bottom manhole, as shown in Figure 43 e), or a top manhole, as shown in Figure 43 a), a clear height of 400 mm between the boiler shell (manhole surround) and the tube assembly in the entry area in the axial direction shall be sufficient, if one width of the entry space (if possible wedge shaped) is at least 600 mm. For smaller spaces, only the upper part of the body or head need enter as shown in Figure 43 c).

14.5.2 If it is necessary to pass from one inspection space into another, for instance a lateral space, it shall be sufficient to have a space with a height of at least 300 mm at its narrowest point (e.g. see Figure 43 e)).

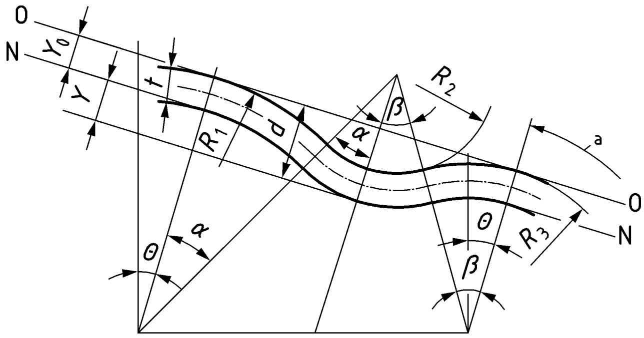
14.6 Accessibility and arrangement of entry and inspection openings

All entry and inspection openings shall be accessible or shall be easily made accessible. When installing pumps, valves, preheaters, frame constructions, foundations, etc., accessibility shall be taken into account. In each case, the arrangement of the entry and inspection opening, along or at right angles to the boiler axis, shall be used to make the inspection conditions as favourable as possible.

Annex A
(informative)

Calculation form for “Walker”-type reverse curve sections or corrugations

The suggested working form presents a method whereby the sustainable pressure of reversed curvature of non-circular reversal chambers maybe calculated as required by 13.1.5.

<table>
<tr><td colspan="3">Design pressure = N/mm²</td><td colspan="3">[a] Minimum in accordance with 13.1.1 but not less than t</td></tr>
<tr><td colspan="3">Design temperature = °C</td><td colspan="3" rowspan="8">
</td></tr>
<tr><td colspan="3">Design stress, f = N/mm²</td></tr>
<tr><td colspan="3">R_1 = mm</td></tr>
<tr><td colspan="3">R_2 = mm</td></tr>
<tr><td colspan="3">R_3 = mm</td></tr>
<tr><td colspan="3">b = mm</td></tr>
<tr><td colspan="3">t = mm (corroded)</td></tr>
<tr><td colspan="3">L, distance between centres of support (≤4 $\sqrt{2\,R\,t}$) mm
where
R is the greater of R_1 or R_3</td></tr>
<tr><td colspan="2">$r_1 = R_1 - t/2$ = mm</td><td colspan="2">$r_2 = R_2 + t/2$ = mm</td><td colspan="2">$r_3 = R_3 - t/2$ = mm</td></tr>
<tr><td colspan="6">$\Theta = \sin^{-1}\left(\frac{r_1 - r_3}{b}\right) =$ °</td></tr>
<tr><td colspan="6">$\alpha = 90 - \cos^{-1}\left[\frac{(r_1+r_2)^2 + b^2 - (r_2+r_3)^2}{2(r_1+r_2)\,b}\right] - \Theta =$ °</td></tr>
<tr><td colspan="6">$\beta = 90 - \cos^{-1}\left[\frac{(r_2+r_3)^2 + b^2 - (r_1+r_2)^2}{2(r_2+r_3)\,b}\right] + \Theta =$ °</td></tr>
<tr><td colspan="6">$d = r_2 - (r_1+r_2)\cos\alpha + r_1 + t =$ mm</td></tr>
<tr><td colspan="6">considering areas of each section —</td></tr>
<tr><td colspan="3">$a_1 = r_1\,\alpha\,\frac{t\,\pi}{180} =$ mm²</td><td colspan="3">$a_3 = r_2\,\beta\,\frac{t\,\pi}{180} =$ mm²</td></tr>
<tr><td colspan="3">$a_2 = r_2\,\alpha\,\frac{t\,\pi}{180} =$ mm²</td><td colspan="3">$a_4 = r_3\,\beta\,\frac{t\,\pi}{180} =$ mm²</td></tr>
<tr><td colspan="3">$A = \Sigma_a =$ mm²</td><td colspan="3"></td></tr>
<tr><td colspan="6">for positions of centroids —</td></tr>
<tr><td colspan="6">$Y_1 = r_1 + t/2 - \frac{\sin\alpha}{\alpha} \times \frac{2}{3}\left[\frac{(r_1+t/2)^3 - (r_1-t/2)^3}{(r_1+t/2)^2 - (r_1-t/2)^2}\right]\frac{180}{\pi} =$ mm</td></tr>
<tr><td colspan="6">$Y_2 = d - r_2 - t/2 + \frac{\sin\alpha}{\alpha} \times \frac{2}{3}\left[\frac{(r_2+t/2)^3 - (r_2-t/2)^3}{(r_2+t/2)^2 - (r_2-t/2)^2}\right]\frac{180}{\pi} =$ mm</td></tr>
</table>

$Y_3 = d - r_2 - t/2 + \frac{\sin\beta}{\beta} \times \frac{2}{3}\left[\frac{(r_2 + t/2)^3 - (r_2 - t/2)^3}{(r_2 + t/2)^2 - (r_2 - t/2)^2}\right]\frac{180}{\pi} =$			mm
$Y_4 = r_3 + t/2 - \frac{\sin\beta}{\beta} \times \frac{2}{3}\left[\frac{(r_3 + t/2)^3 - (r_3 - t/2)^3}{(r_3 + t/2)^2 - (r_3 - t/2)^2}\right]\frac{180}{\pi} =$			mm
moments about 0–0 —			
$Y_0 = \frac{a_1 Y_1 + a_2 Y_2 + a_3 Y_3 + a_4 Y_4}{\Sigma_a} =$	mm	$Y = d - Y_0 =$	mm
for second moments of area about neutral axis N-N —			
$l_1 = \left[\frac{\alpha\pi}{90} + \sin 2\alpha\right] \times \left[\frac{(r_1 + t/2)^4 - (r_1 - t/2)^4}{16}\right] - a_1 (r_1 + t/2 - Y_1)^2 + a_1 (Y_0 - Y_1)^2 =$			mm^4
$l_2 = \left[\frac{\alpha\pi}{90} + \sin 2\alpha\right] \times \left[\frac{(r_2 + t/2)^4 - (r_2 - t/2)^4}{16}\right] - a_2 (r_2 + t/2 - d + Y_2)^2 + a_2 (Y_2 - Y_0)^2 =$			mm^4
$l_3 = \left[\frac{\beta\pi}{90} + \sin 2\beta\right] \times \left[\frac{(r_2 + t/2)^4 - (r_2 - t/2)^4}{16}\right] - a_3 (r_2 + t/2 - d + Y_3)^2 + a_3 (Y_3 - Y_0)^2 =$			mm^4
$l_4 = \left[\frac{\beta\pi}{90} + \sin 2\beta\right] \times \left[\frac{(r_3 + t/2)^4 - (r_3 - t/2)^4}{16}\right] - a_4 (r_3 + t/2 - Y_4)^2 + a_4 (Y_0 - Y_4)^2 =$			mm^4
$l_n = \Sigma\, l =$			mm^4
$P_{max} = \frac{8 f I_n}{Y L^2 b \cos\Theta} =$	N/mm^2	.	
If $P_{max} > P_{design}$ then the section under consideration is acceptable			

Annex B
(normative)

Furnace calculation temperature

B.1 Calculation of the maximum and the middle furnace wall temperature

If the material temperature according to the Formula (B.2) exceeds 420 °C creep shall be considered at strength calculation according to Clause 13. The relevant calculations of Clause 13 shall be performed both for $R_{p0,2tc}$ and for $R_{m/100\,000/tc}$.

Maximum furnace temperature $\vartheta_{m;f}$ [°C] at inside surface:

$$\vartheta_{m;f} = \vartheta_W + \varphi_1 \times (1/h + e_s/\lambda_s + e_{fa}/\lambda) \quad \text{(B.1)}$$

Furnace temperature at the middle of the wall thickness ϑ_{mg} [°C]:

$$\vartheta_{mg} = \vartheta_{m;f} - 0{,}5 \times \varphi_1 \times e_{fa}/\lambda \quad \text{(B.2)}$$

with:

ϑ_W [°C] saturation temperature at PS

φ_1 [W/mm²] maximum surface heat flux

$$\varphi_1 = k \times \eta \times \Phi_b / A \quad \text{(B.3)}$$

with a maximum limit of 0,33 W/mm².

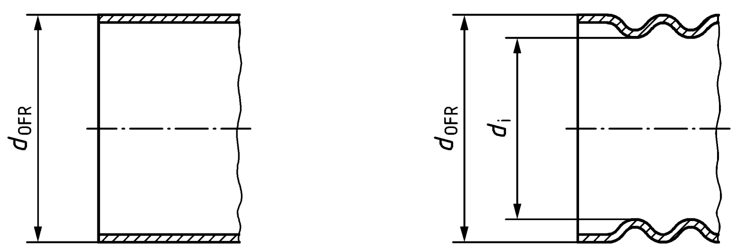
k [-]: contrast factor (ratio between the maximum and the average heat flux density in the furnace wall)

$$\text{Oil: } k = 0{,}93 + 0{,}16 \times l / D_g + 0{,}008 \times (l / D_g)^2 \quad \text{(B.4)}$$

$$\text{Gas: } k = 1 + 0{,}1 \times l / D_g \quad \text{(B.5)}$$

D_g [mm] calculation diameter of furnace (see Figure B.1)

l [mm] length of furnace (see Figure B.2)

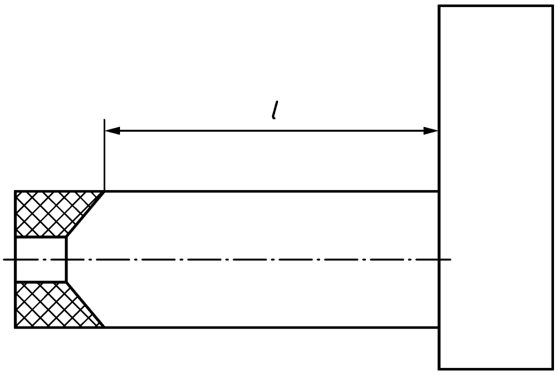


Key

d_i inside diameter

d_{OFR} outside diameter

Figure B.1 — Calculation diameter of the furnace $D_g = d_{OFR}$ respectively $D_g = (d_{OFR} + d_l)$ 0,5



Key

l free length of the furnace

Figure B.2 — Free length of the furnace

η [-]: efficiency of furnace

$$\eta = (\vartheta_{f;th} - \vartheta_{f;e}) / \vartheta_{f;th} \quad \text{(B.6)}$$

$\vartheta_{f;e}$ [°C]: flame temperature at the end of the combustion chamber (see Figure B.2)

$$\vartheta_{f;e} = 0{,}5 \{[2 (u^2 + 4 \text{ m} (\vartheta_{f;th} + 273°C))^{0,5} - u]^{0,5} - u^{0,5}\} - 273 °C \quad \text{(B.7)}$$

m [°C³]: service parameter

$$\text{m} = 1 / (\varepsilon \times \sigma \times \vartheta_{f;th}) \times \Phi_b / A \quad \text{(B.8)}$$

σ [W/mm² K⁴]: 5,67 10^{-14} Stefan – Boltzmann - constant

ε [-]: Emission-coefficient (see Table B.1)

$\vartheta_{f;th}$ [°C]:Theoretic flame temperature (see Table B.1)

Table B.1 — Emission-coefficient - Theoretic flame temperature

Fuel	$\vartheta_{f;th}$ [°C]	ε
oil	2 050	0,7
gas	1 950	0,5

Φ_b [W] firing heat input $\Phi_b = H \times 10^{-6}$ W

A [mm²]: furnace surface

$$A = \pi \times D_g \times (l + 0{,}25 \times D_g) \quad \text{(B.9)}$$

u [°C²]: service parameter

$$u = \{(a + 1)^{1/3} - (a - 1)^{1/3}\} \times (0{,}5 \times \text{m}^2)^{1/3} \quad \text{(B.10)}$$

a: service parameter

$$a = \{1 + [256 \times (\vartheta_{f;th} + 273°C)^3] / (27 \times \text{m})\}^{0,5} \quad \text{(B.11)}$$

h [W/mm² K]: heat transition coefficient for furnace: water (normally h = 0,018 W/mm²K)

e_s [mm]: furnace facing (normally minimum e_s = 0,1 mm for PS ≤ 20 bar and water quality in accordance with EN 12953-10)

λ_s [W/mm K]: thermal conductivity of the furnace facing material

λ_s = 0,001 2 W/mm K for boiler scale

e_{fa} [mm]: calculated wall thickness of furnace with allowances

λ [W/mm K]: thermal conductivity of the furnace material (see Table B.2)

Table B.2 — Thermal conductivity λ in W/mm K as function of the temperature

	20°C	**100°C**	**200°C**	**300°C**	**400°C**	**500°C**
P265GH **P295GH** **P355GH**	0,054 7	0,053 8	0,050 5	0,047 0	0,043 5	0,040 0

Annex C
(informative)

Calculation of tube plate temperatures

C.1 General

This annex provides a method for the calculation of the hot-face metal temperature and the average (design) temperature of tube plates within the tube nest.

The calculation takes into account the effects under steady-state conditions of heat transfer

a) from the hot gas to the tube plate face and tube inside surfaces by convection, including the tube entrance effect, and radiation, including radiation interchange in the reversal chamber;

b) by thermal conduction through the tube plate and tube walls from the tube plate face and tube inside surfaces to the water side surfaces, assuming adequate thermal contact between tube and plate; and

c) by nucleate boiling from the water side surfaces.

The method and design curves have been developed from published heat transfer data and contain some simplifying approximations which tend to be self-compensating. Calculated and measured temperatures have shown good agreement where complete data are available.

C.2 Symbols

For the purposes of this annex the symbols given in EN 12953-1:2012, Table 1 and Table C.2 apply.

Table C.1 — Symbols

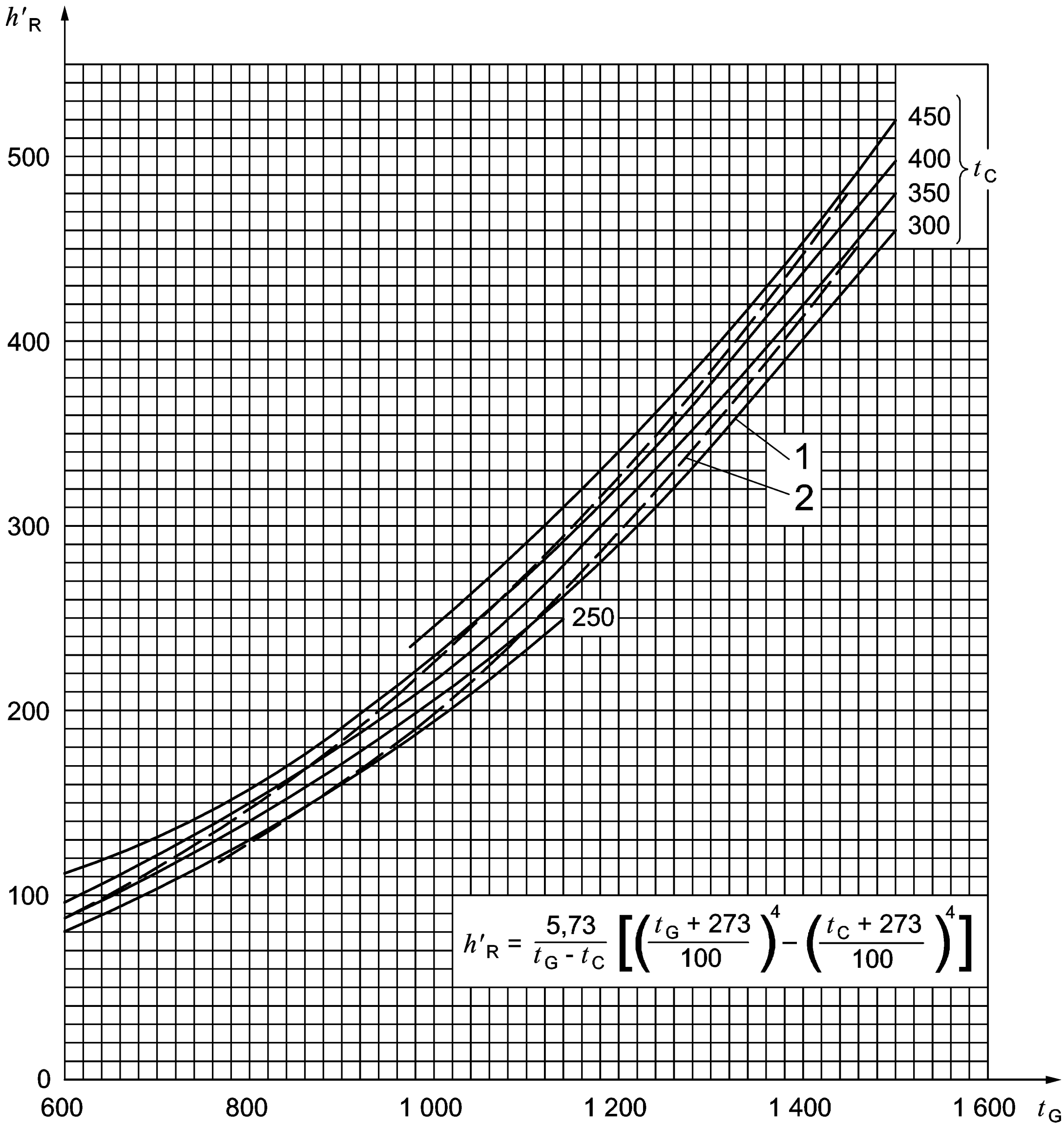
Symbol	Description	Unit
A	Heat input area to the tube plate element from the tube inside surfaces (see Figure C.7).	mm^2
A_C	Total effective water-cooled surface area in the reversal chamber.	mm^2
A_R	Total refractory surface area in the reversal chamber.	mm^2
a	Heat input area to the tube plate element from the tube plate face (see Figure C.8).	mm^2
C	Correction factor for tube to tube plate contact thermal resistance.	-
d	Inside diameter of the convection tube.	mm
D	Reversal chamber inside diameter (for cylindrical chambers).	mm
e	Tube plate thickness.	mm
F	Overall exchange factor for radiation interchange in the reversal chamber (see Figure C.2).	-
G	Tube specific gas flow rate.	$kg/(m^2 \cdot s)$
h_{CE}	Tube entrance convection coefficient (see Figure C.6)	$W/(m^2 \cdot K)$
h_{CO}	Corrected basis convection coefficient (see Figure C.5)	$W/(m^2 \cdot K)$
h'_{CO}	Hypothetical basis convection coefficient (see Figure C.4)	$W/(m^2 \cdot K)$
h_m	Tube plate thermal conductance.	$W/(m^2 \cdot K)$
h_R	Radiation coefficient for the tube plate face.	$W/(m^2 \cdot K)$
h'_R	Radiation coefficient for black exchange (see Figure C.1).	$W/(m^2 \cdot K)$
h_t	Weighted average heat transfer coefficient.	$W/(m^2 \cdot K)$
L	Reversal chamber inside length (for cylindrical chambers).	mm
L_B	Reversal chamber radiation beam length.	mm
N	Water side constant, = 4 000.	$W/(m^2 \cdot K)$
p	Average pitch between the tube centres.	mm
t	Tube plate average (design) temperature	°C
t_C	Initial estimate of t_M	°C
t_G	True gas temperature at the tube entrance.	°C
t_M	Tube plate hot-face metal temperature.	°C
t_S	Boiler water temperature.	°C
β	Tube plate average temperature factor (see Figure C.12).	-
η	Heat transfer factor for the tube plate element (see Figure C.10).	-
λ	Tube plate thermal conductivity:	$W \cdot mm/(m^2 \cdot K)$
Φ	Tube plate hot-face temperature factor (see Figure C.11).	-

C.3 Calculation method

C.3.1 Radiation coefficients

The radiation coefficient h'_R for black exchange, i.e. emissivity = 1, F = 1 shall be determined from Figure C.1. The gas temperature t_G at tube entry shall be the true value as would be measured by a multishield high-velocity suction pyrometer. (An ordinary thermocouple will always read low; the error may be up to 300 °C.)

An initial value t_C for the tube plate hot-face metal temperature shall be assumed. Typical values shown on Figure C.1 shall usually avoid the necessity for reiteration.



Key

1 typical dry back curve

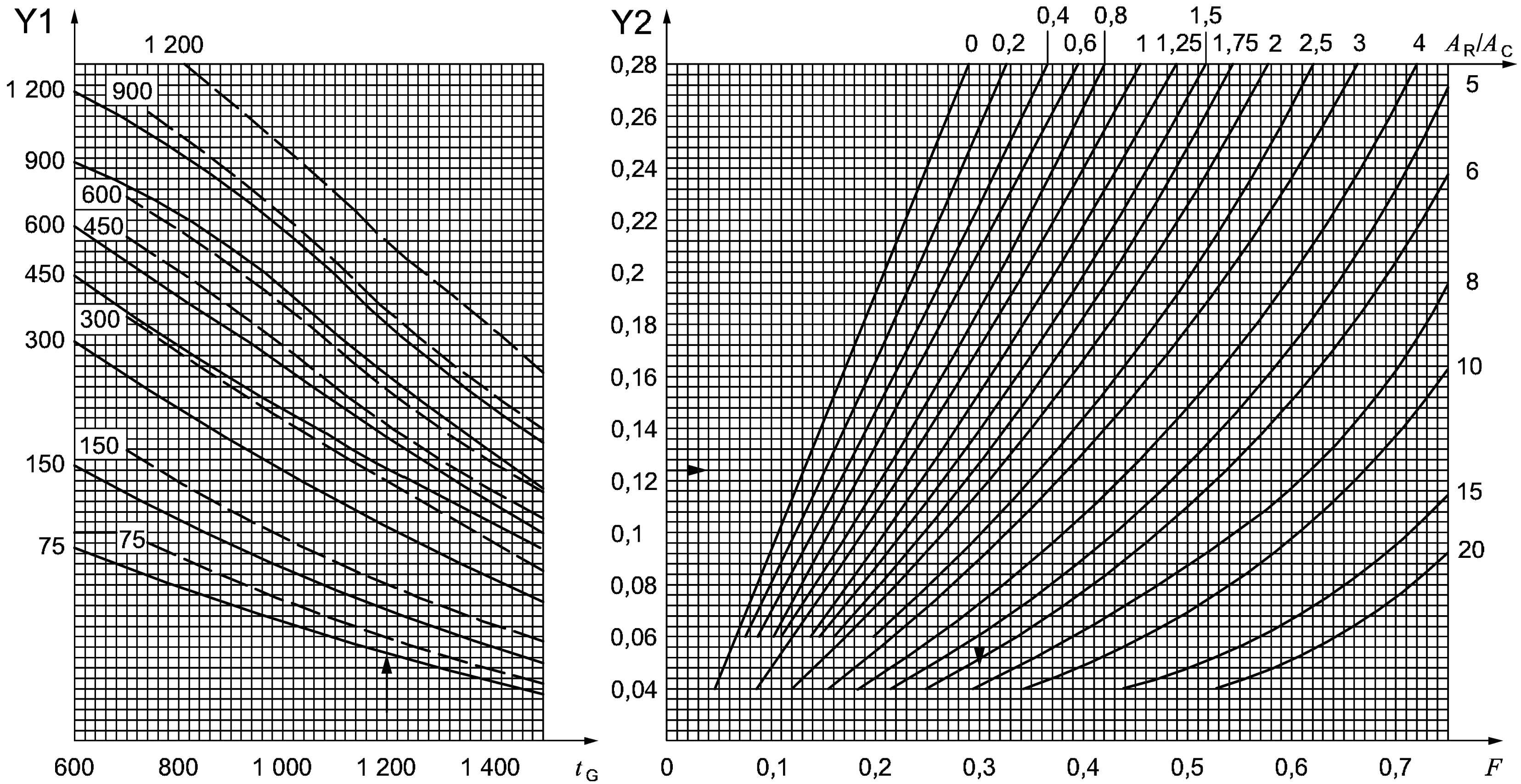
2 typical wet back curve

t_G true gas temperature at the tube entry (in °C)

h'_R radiation coefficient (in W/(m² · K))

Figure C.1 — Radiation coefficient h'_R for black exchange (F = 1)

The emissivity of the gas shall depend on the gas analysis, temperature, partial pressures and the beam length in the reversal chamber. The curves in Figure C.2 are based on the excess air normally used in directly fired boilers. For products of coal combustion, it is recommended that the natural gas curve be used to allow for particle radiation. For other gas mixtures, the gas emissivity should be determined from a text on radiant heat transfer, e.g. [1].



Key

Y1	beam length (in mm)
Y2	gas emissivity
t_G	true gas temperature at the tube entry (in °C)
F	overall exchange factor
— — —	natural gas and coal
———	oil fuels

Figure C.2 — Determination of overall exchange factor *F*

The radiation beam length L_B for a cylindrical reversal chamber shall be given by the following formula:

$$L_B = \frac{0{,}83\,L}{L/D + 0{,}5} \tag{C.1}$$

For chambers which are not cylindrical, the radiation beam length shall be given by the following formula:

$$L_B = 3{,}3\frac{V_c}{A_{CS}} \tag{C.2}$$

where

V_C is the chamber volume;

A_{CS} is the chamber surface area.

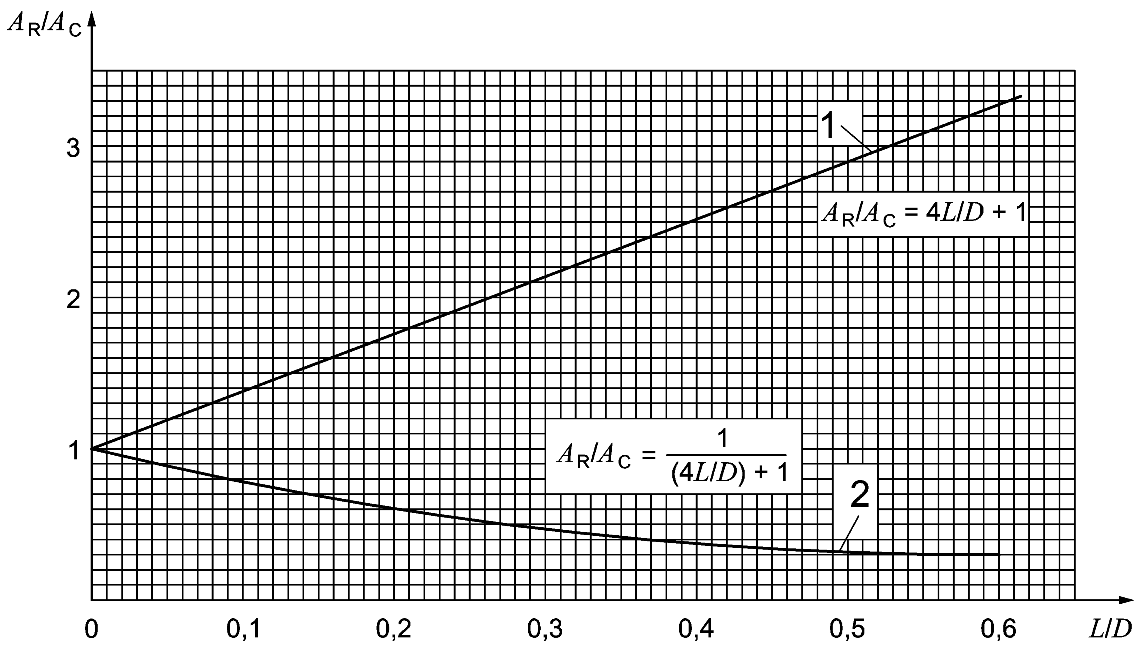
In calculating the chamber surface area no reduction shall be made for tube holes or the furnace tube opening.

For chambers containing refractory linings, the ratio of the total effective (reflecting) refractory surface area to the effective cooled (absorbing) surface area in the chamber, A_R/A_C shall be obtained from Figure C.3

A_C includes the total area enclosed within the tube plate perimeter, i.e. no reduction for tube holes or the furnace tube opening.

For cylindrical chambers A_R/A_C shall be obtained from Figure C.3.

For fully water-cooled chambers A_R/A_C = 0.



Key

1 dry back

2 semi-wet back

NOTE For a non-cylindrical chamber, include the total superficial area of the tube plate in A_C (no reduction for tube holes or furnace tube openings).

Figure C.3 — A_R/A_C for a cylindrical chamber with diameter D and length L

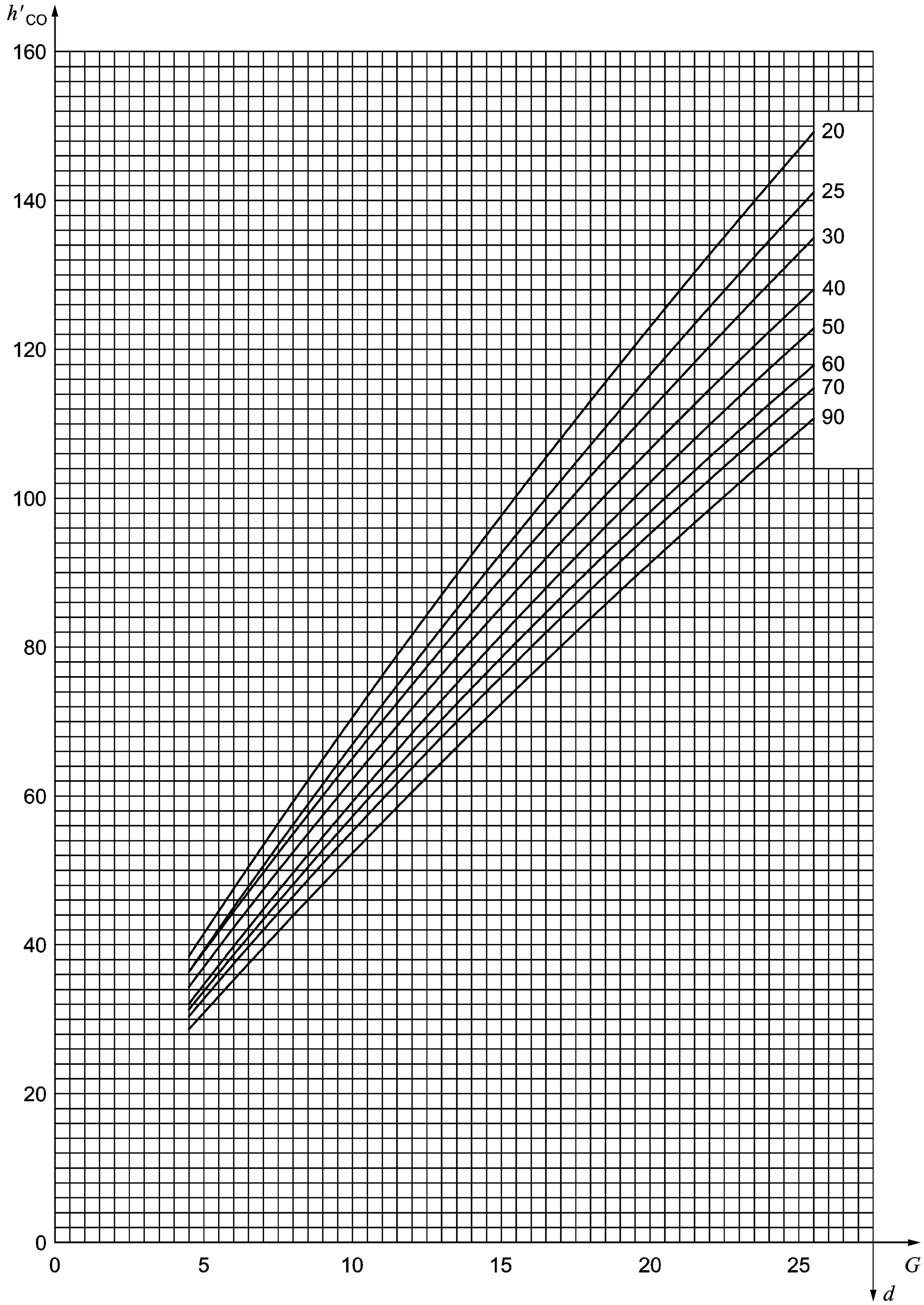
The overall exchange factor F shall be determined from Figure C.2, and then the radiation coefficient for the tube plate face shall be given by the following formula:

$$h_R = F\, h'_R \qquad \text{(C.3)}$$

Radiation to the tube inside surfaces shall be taken into account by use of the coefficient 0,5 h_R in the equation for the weighted average heat transfer coefficient h_t (see C.3.3).

C.3.2 Convection coefficients

The hypothetical basis convection coefficient h'_{CO} shall be dependent on the specific gas flow rate G in the convection tubes and on the tube inside diameter d. For the products of combustion of oil fuels, natural gas and coal, h'_{CO} shall be determined from Figure C.4.



Key

d tube inside diameter in mm

G tube flow rate in kg/(m² · s)

h'_{CO} hypothetical basis convection coefficient in W/(m² · K)

NOTE $$h'_{CO} = 20{,}2\,\frac{G^{0{,}8}}{d^{0{,}2}} \qquad \text{(C.4)}$$

Figure C.4 — Basis convection coefficient h'_{CO}

The correction factor h_{CO}/h'_{CO} for the tube entry gas temperature shall be determined from Figure C.5. Then the corrected basis convection coefficient for fully developed tube flow at temperature t_G shall be determined by the following formula:

$$h_{CO} = h'_{CO} \left(\frac{h_{CO}}{h'_{CO}} \right) \quad \text{(C.5)}$$

For other gases where the values of specific heat, thermal conductivity or viscosity are different from those for the products of combustion of oil or natural gas, the value of h_{CO} shall be deduced from the equation for fully developed flow inside tubes as follows:

$$Nu = 0{,}023\, Re^{0{,}8}\, Pr^{\,0{,}33} \quad \text{(C.6)}$$

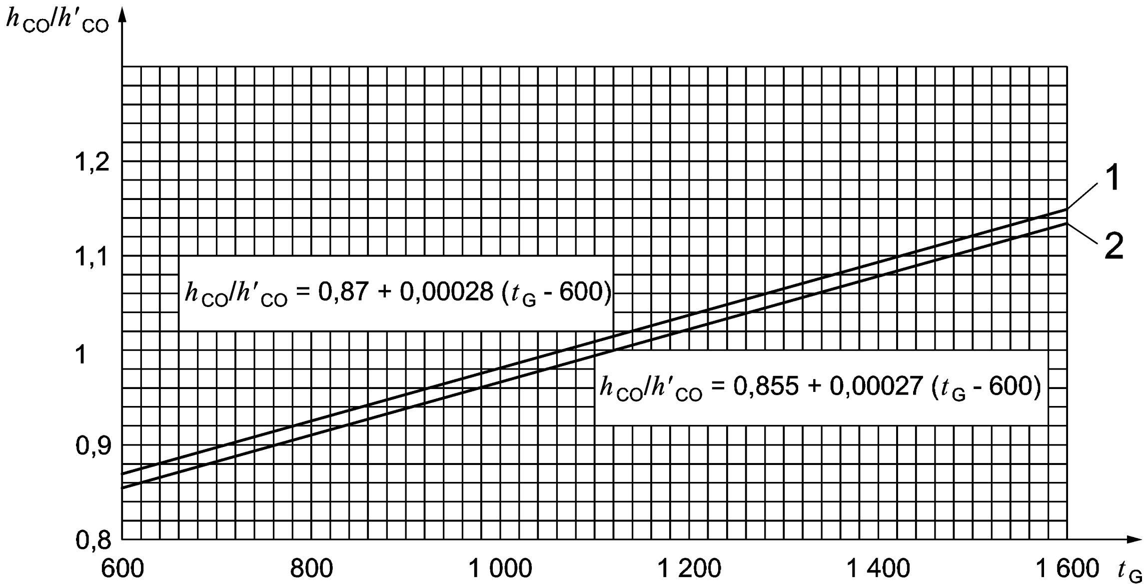
where

Nu is the Nusselt number, based on the tube inside diameter d,

Re is the Reynolds number, based on the tube inside diameter d,

Pr is the Prandtl number.

(see, for example, [1]).



Key

1 natural gas

2 oil fuels and coal

t_G true gas temperature at tube entry in °C

Figure C.5 — Determination of correction factor

The correction factor h_{CE}/h_{CO} for the tube entrance region shall be determined from Figure C.6. Then the average convection coefficient, h_{CE}, for the tube inside surface over the effective length for heat input to the tube plate, shall be determined by the following formula:

$$h_{CE} = h_{CO} \left(\frac{h_{CE}}{h_{CO}} \right) \quad \text{(C.7)}$$

Convective heat transfer to the tube plate face shall be taken into account by the use of the coefficient h_{CO} in the equation for the weighted average heat transfer coefficient h_t (see C.3.3).

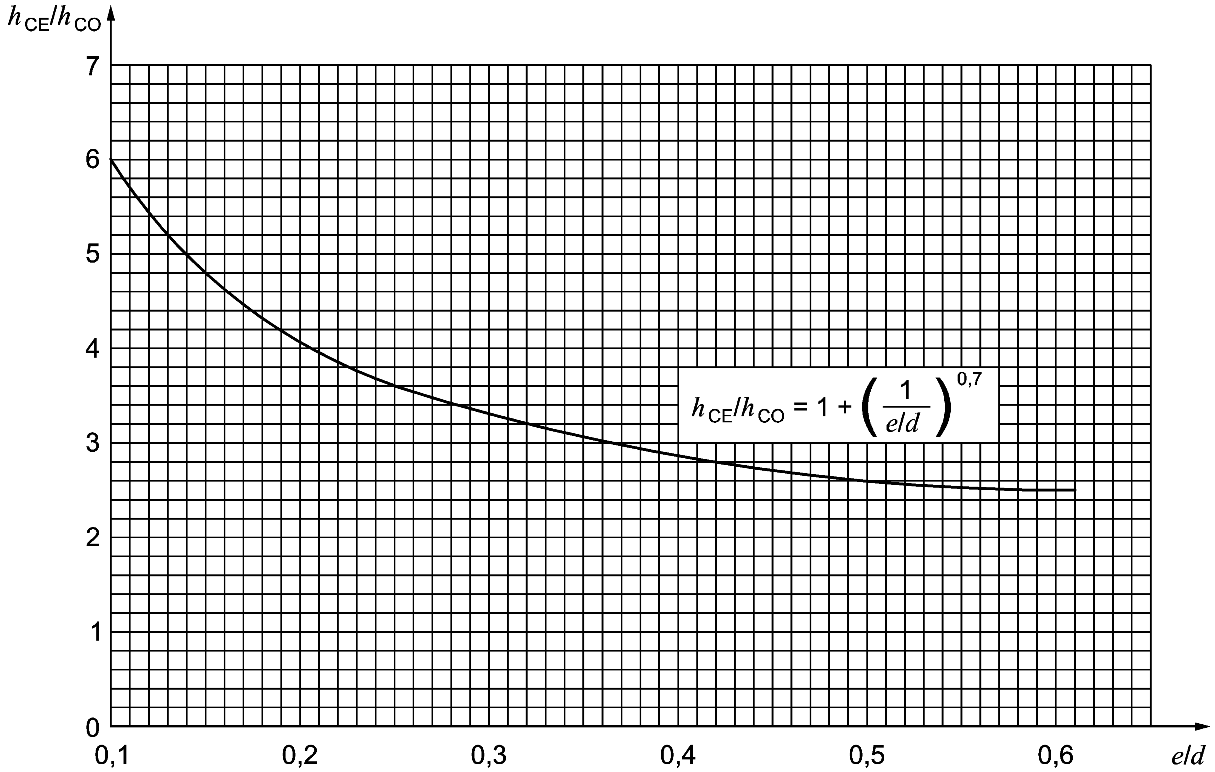


Figure C.6 — Determination of correction factor

C.3.3 Weighted average gas-side heat transfer coefficient

For the tube plate element, bounded by tube inside surfaces and planes containing tube centre-lines, the heat input areas A (tube inside surfaces) and a (tube plate face) shall be determined from Figures C.7 and C.8.

The weighted average heat transfer coefficient shall then be calculated as follows:

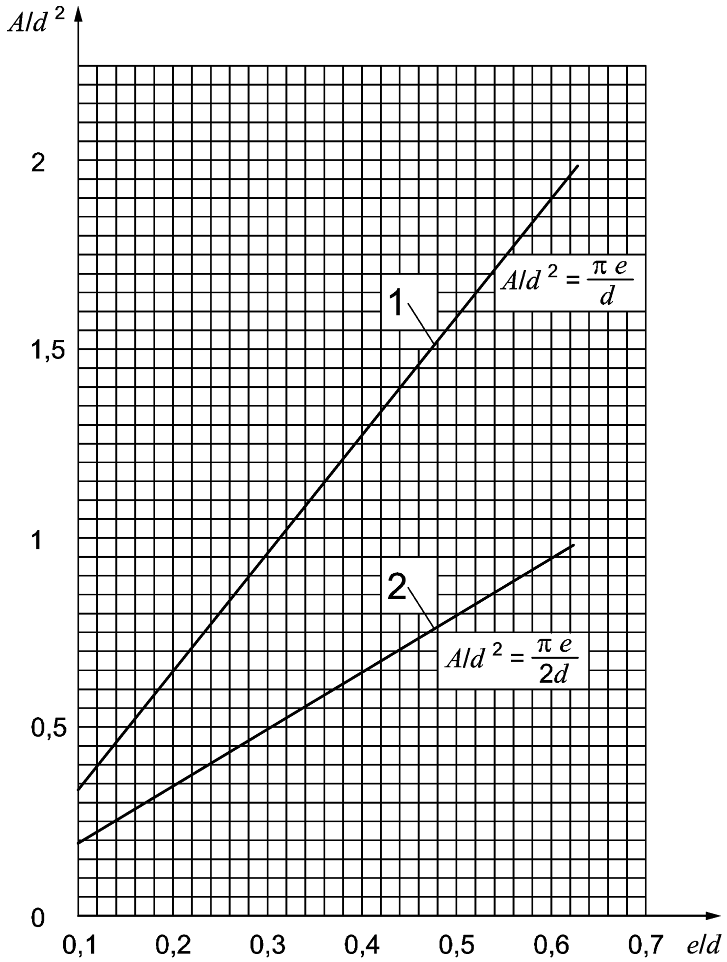
$$h_t = \frac{\frac{CA}{d_2}\left(h_{CE} + 0{,}5\, h_R\right) + \frac{a}{d^2}\left(h_{CO} + h_R\right)}{\left(\frac{A}{d^2} + \frac{a}{d^2}\right)} \tag{C.8}$$

where

C = 0,9 for tubes expanded only;

C = 0,95 for tubes expanded and welded,

C = 1 for tubes full penetration welded.

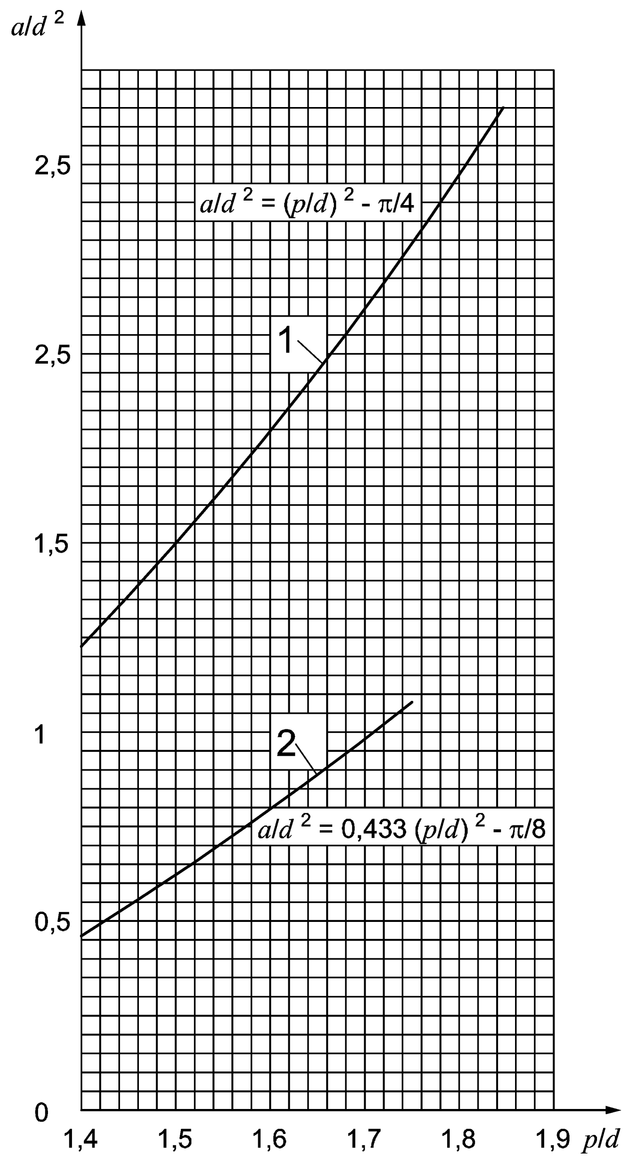


Key

1 Square pitch

2 Triangular pitch

Figure C.7 — Non-dimensional tube area



Key

1 square pitch

2 triangular pitch

Figure C.8 — Non-dimensional plate area

C.3.4 Tube plate thermal conductance

The tube plate thermal conductance shall be given by the following formula:

$$h_{\mathrm{m}} = \frac{\lambda}{e} \qquad \text{(C.9)}$$

where

λ = 40 000 for steel grades 460 and 490 (P295GH and P355GH); and

λ = 45 000 for steel grades 400 and 430 (P235GH and P265GH).

C.3.5 Water side heat transfer

Heat transfer conditions at the water side surfaces are taken into account in the equations for the tube plate metal temperatures by use of the constant N.

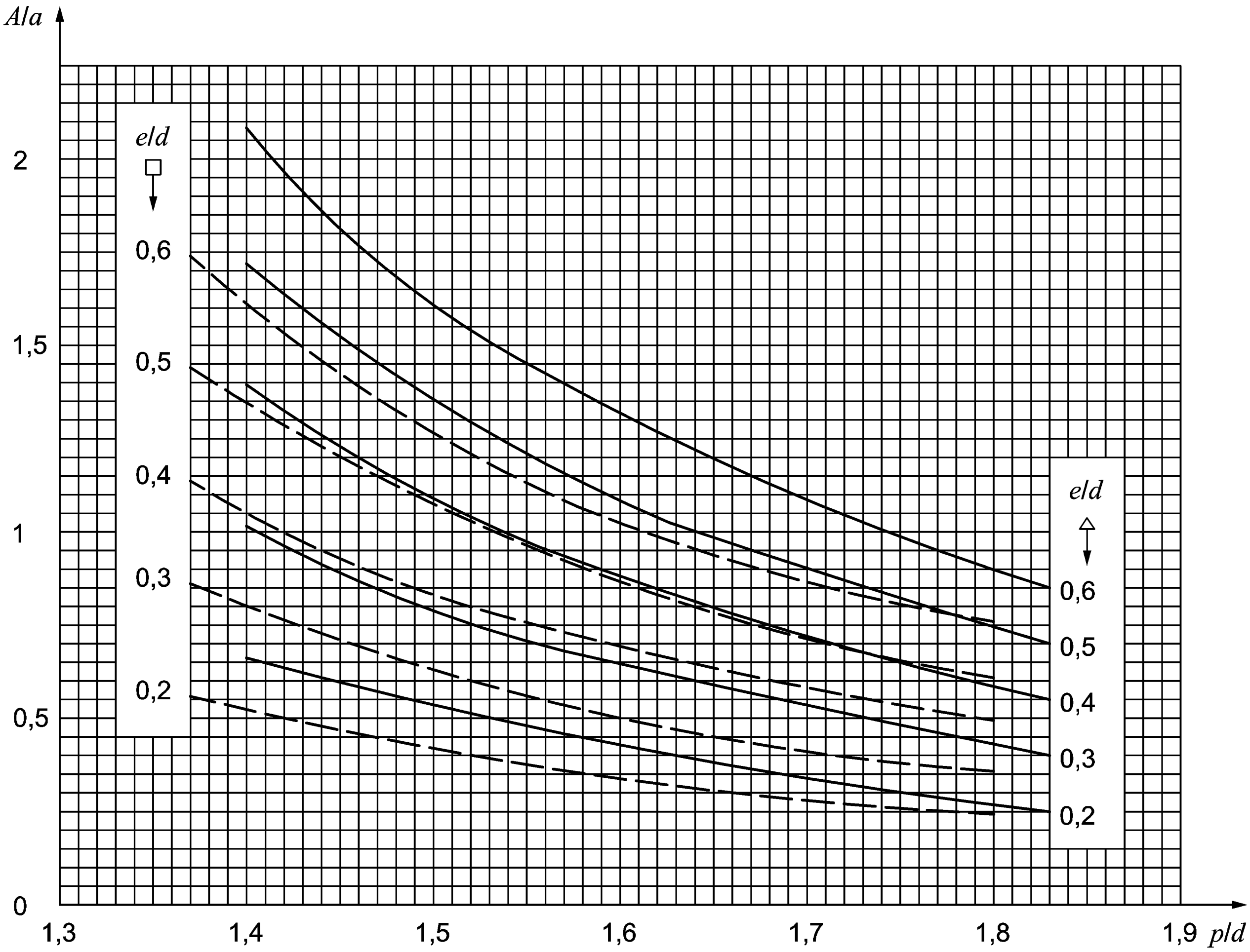
C.3.6 Tube plate temperatures

The following equations for the tube plate hot-face and average metal temperatures are based on equations developed by Gardner [2]:

$$t_M = t_S + 15 + (t_G - t_S)\left(1 - \frac{\Phi}{1 + (\eta\, h_t / N)}\right) \tag{C.10}$$

$$t = t_S + 15 + (t_G - t_S)\left(1 - \frac{\beta}{1 + (\eta\, h_t / N)}\right) \tag{C.11}$$

The factors η, Φ and β are dependent on A/a (see Figure C.9) and on h_t/h_m and shall be obtained from Figures C.10 to C.12.



Key

— — —	square pitch
———	triangular pitch

Figure C.9 — Tube/plate area ratio

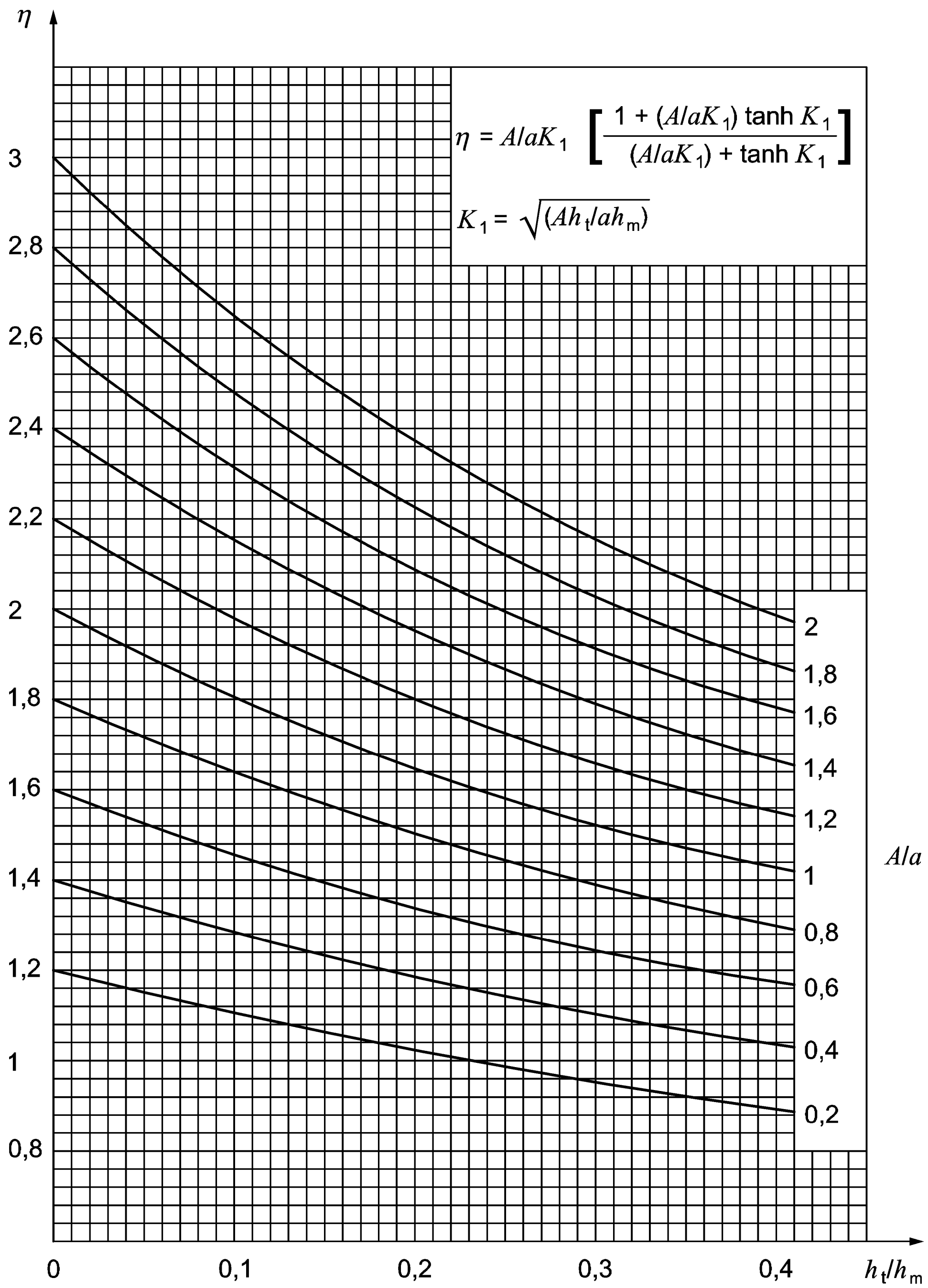


Figure C.10 — Factor η

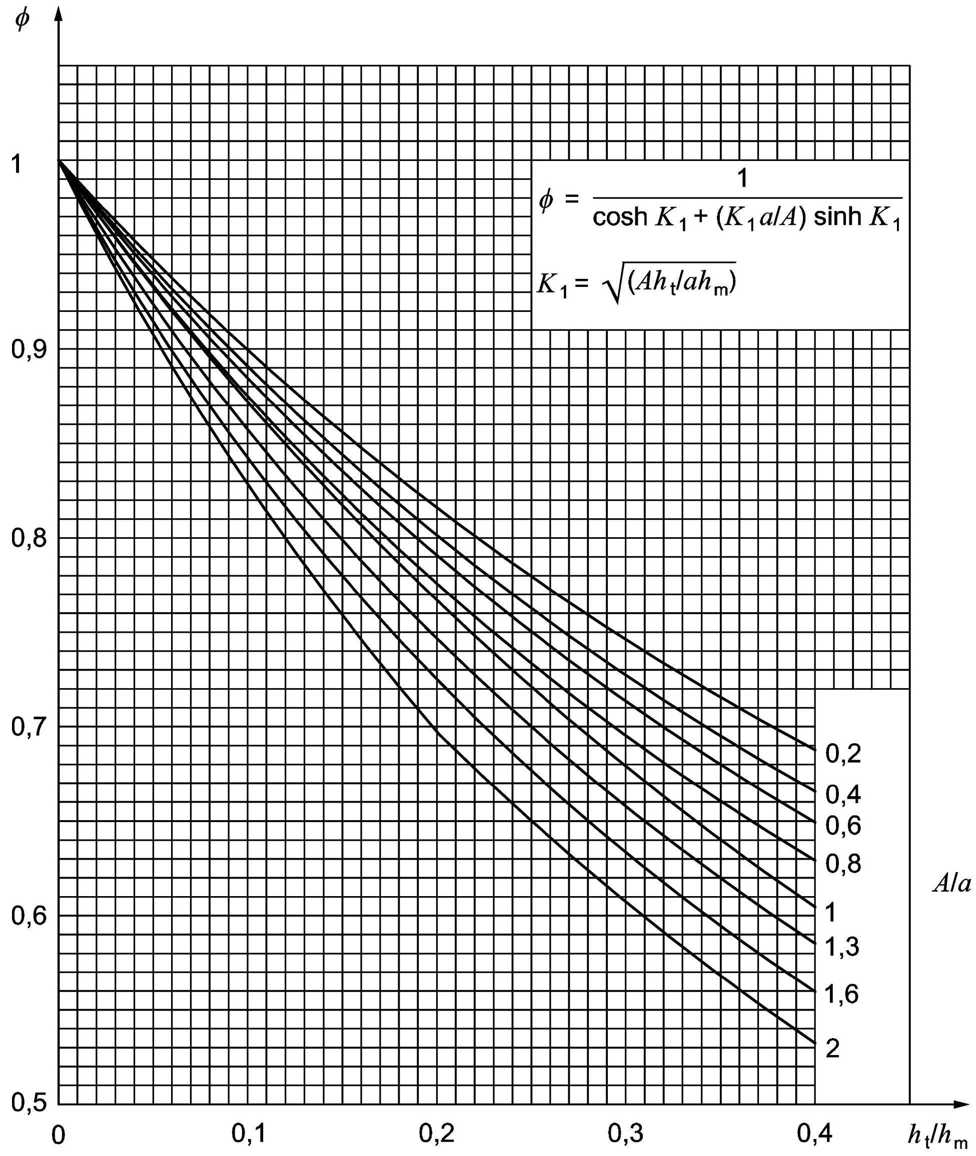


Figure C.11 — Factor Φ

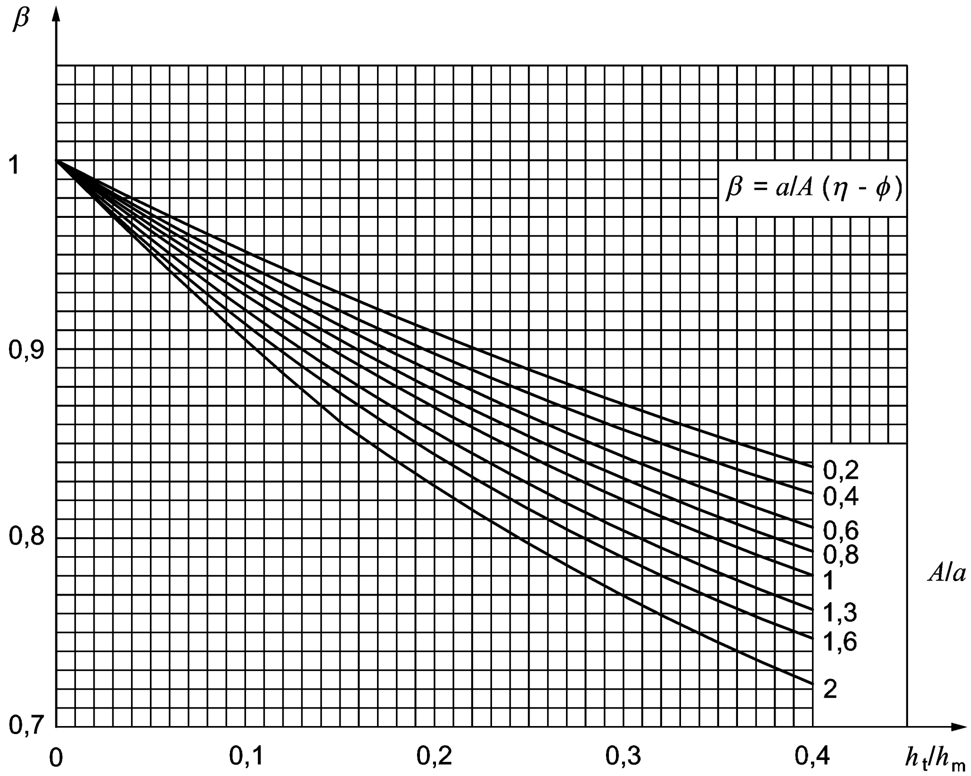


Figure C.12 — Factor β

C.4 Example of a calculation carried out using the method given in C.3

C.4.1 Design data assumed

Fuel: natural gas

Boiler: multitubular waste heat with refractory-lined hot-gas chamber

Specified inlet gas temperature: 900 °C

Boiler design pressure: 1,1 N/mm²

Saturation temperature: t_S = 188 °C

Boiler tubes:

inside diameter d = 56,3 mm

pitch, triangular p = 88 mm

gas flow rate G = 11 kg/(m² · s)

Tubeplate:

thickness e = 22 mm

steel group 1

Tube end attachment: expanded and welded

Inlet gas chamber:

cylindrical, refractory lined on wrapper and back plates

inside diameter D = 1 800 mm

inside length L = 1 000 mm

C.4.2 Calculation of radiation coefficient

The calculation of the radiation coefficient h_R shall be carried out as described in C.3.1.

From Figure C.1, using an assumed value of t_C = 350 °C indicated by the for external chamber typical dry back curve, h'_R = 185 W/(m² · K).

Radiation beam length

$$L_B = \frac{0,83 \times 1\,000}{1\,000/1\,800 + 0,5} = 786 \text{ mm}$$

From Figure C.3, $\frac{A_R}{A_C} = 3,15$, where $\frac{L}{D} = 0,555$.

From Figure C.2, F = 0,58.

Therefore,

h_R = 0,58 × 185 = 107,3 W/(m² · K)

C.4.3 Calculation of convection coefficients

The calculation of convection coefficients h_{CO} and h_{CE} shall be carried out as described in C.3.2.

From Figure C.4, h'_{CO} = 61 W/(m² · K).

From Figure C.5, $\frac{h_{CO}}{h'_{CO}} = 0,952$.

Therefore,

h_{CO} = 0,952 × 61 = 58,1 W/(m² · K)

From Figure C.6 ist $\frac{h_{CE}}{h_{CO}} = 2,9$, where $\frac{e}{d} = \frac{22}{56,3} = 0,391$.

Therefore,

h_{CE} = 58,1 × 2,9 = 168,5 W/(m² · K)

C.4.4 Calculation of weighted average gas-side heat transfer coefficient

The calculation of the weighted average gas-side heat transfer coefficient h_t shall be carried out as described in C.3.3.

From Figure C.7, $\frac{A}{d^2} = 0,6$, where $\frac{e}{d} = 0,391$ triangular pitch.

From Figure C.8, $\frac{a}{d^2} = 0,67$, where $\frac{p}{d} = \frac{88}{56,3} = 1,563$.

For tubes expanded and welded C = 0,95.

Therefore,

$$h_t = \frac{0,95 \times 0,6\left(168,5 + 0,5 \times 107,3\right) + 0,67\left(58,1 + 107,3\right)}{0,6 + 0,67} = 187 \text{ W}/\left(\text{m}^2 \cdot \text{K}\right)$$

C.4.5 Calculation of tube plate thermal conductance

The calculation of the tube plate thermal conductance h_m shall be carried out as described in C.3.4.

For steel group 1 λ = 45 000 W · mm/(m² · K) (see C.2).

Therefore,

$$h_{\mathrm{m}} = \frac{45\,000}{22} = 2\,045\ \mathrm{W}/\left(\mathrm{m}^2 \cdot \mathrm{K}\right)$$

C.4.6 Calculation of tube plate temperatures

The calculation of tube plate temperatures t and t_{M} shall be carried out as described in C.3.6.

$$\frac{h_{\mathrm{t}}}{h_{\mathrm{m}}} = \frac{187}{2\,045} = 0{,}09144$$

From Figure C.9, $\frac{A}{a} = 0{,}9$.

From Figures C.10, C.11 and C.12,

η = 1,72

Φ = 0,885

β = 0,935

Therefore, the tube plate hot-face metal temperature shall be given by

$$t_{\mathrm{M}} = 188 + 15 + (900 - 188)\left[1 - \frac{0{,}885}{1 + \frac{1{,}72 \times 187}{4\,000}}\right] = 332\,°C$$

This is below the limit given in 6.1 and shall be therefore satisfactory.

The tube plate average (design) metal temperature shall be given by

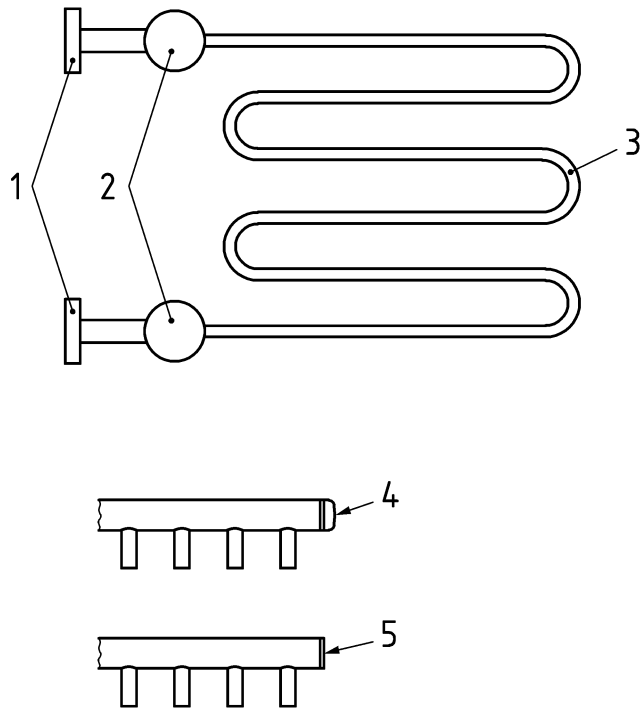
$$t = 188 + 15 + (900 - 188)\left[1 - \frac{0{,}935}{1 + \frac{1{,}72 \times 187}{4\,000}}\right] = 299\,°C$$

Annex D
(normative)

Economizer and superheater with water tube design connected to the shell boiler

D.1 General

This Annex applies to economisers and superheaters with water tubes connected to a shell boiler. Typical elements of these components are shown in Figure D.1.



Key

1 inlet or outlet of steam or water (tubes with flanges)

2 header (tube)

3 heat transfer tubes (tubes with or without fins)

4 header with torispherical head

5 header with flat set-in plate

Figure D.1 — Typical elements of an economizer or superheater

D.2 Design of economizer and superheater connected to shell boilers

D.2.1 Economizer and superheater connected to shell boilers shall mainly be designed according to EN 12952-3:2011. The following exceptions shall be taken into account:

a) Instead of EN 12952-3:2011, 5.5 concerning load cycles, the requirements of 5.1 of this Part of this European Standard shall apply;

b) All weld factors given in 5.4 of this Part of this European Standard are applicable for the economizer and superheater;

c) Being part of the shell boiler the corrosion allowance c_2 for the economizer and superheater shall be adopted from the boiler;

d) The minimum wall thicknesses for header and tubes given in EN 12952-3:2011, 7.1.1 shall be substituted by the minimum wall thickness defined in Table 7 of this Part of this European Standard;

e) The minimum wall thickness of nozzles given in EN 12952-3:2011, 8.3.2.2 d) shall be substituted by the minimum wall thickness defined in Table 7 of this this Part of this European Standard;

f) Flat unstayed removable closures at headers, e.g. blind flanges according to EN 1092-1:2007+A1:2013, are permitted without pressure limit given in EN 12952-3:2011, 10.4;

g) For fittings such as caps, T-pieces, reducers, elbows, EN 10253-2:2007 can apply.

D.2.2 The test pressure shall be determined individually for the economizer and superheater according to EN 12952-3:2011, 5.7.4.3. If this test pressure for an economizer is lower than the test pressure of the boiler, the value of the boiler shall be adopted from the economizer.

Annex E
(informative)

Significant technical changes between this European Standard and the previous edition

Clause/Paragraph/Table/Figure	Change
2 / Normative references	References updated.
3 / Terms and definitions	Definitions added.
5.5 / Thermal design of furnace tubes	Revision of the Clause.
6 / Calculation temperature and nominal design stress	Revision of the Clause.
8 / Openings and branches in cylindrical shells	Revision of the Clause.
10 / Supported flat plates, stays and stiffeners	Revision of the Clause.
12.3.2 / Departure from circularity of the tube bends	Revision of the Clause.
12.4 / Smoke tubes	Revision of the Clause.
14 / Access and inspection openings	Revision of the Clause.
Annex B / Furnace calculation temperature	New Annex introduced.
Annex D / Economizer and superheater with water tube design connected to the shell boiler	New Annex introduced.
Annex E / Significant technical changes between this European Standard and the previous edition	New Annex introduced.
Annex ZA / Relationship between this European Standard and the Essential Requirements of EU Directive 2014/68/EU	Update of the Annex.
NOTE The technical changes referred include the significant technical changes from the EN revised but is not an exhaustive list of all modifications from the previous version.	

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of EU Directive 2014/68/EU aimed to be covered

This European Standard has been prepared under a Commission's standardization request M/071 "Mandate to CEN for standardization in the field of Pressure equipment" to provide one voluntary means of conforming to Essential Requirements of the New Approach Pressure Equipment Directive 2014/68/EU.

Once this standard is cited in the Official Journal of the European Union under that Directive, compliance with the normative clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive and associated EFTA regulations.

Table ZA.1 — Correspondence between this European Standard and Directive 2014/68/EU on Pressure Equipment

Essential Safety Requirements (ERs) of Directive 2014/68/EU on Pressure Equipment Annex I	Clause(s)/subclause(s) of this EN 12953–3	Qualifying remarks/notes
2.1	5.1 to 5.8	Design — general
7.4	5.7.4	Hydrostatic test pressure
2.6	5.8	Corrosion or other chemical attack
2.2.2 and 2.2.3	Clauses 6 to 13	Design for adequate strength
2.2.1	6.1	Operating temperatures
7.1.2	6.2	Allowable stresses
2.4	Clause 14	Means of examination

WARNING 1 — Presumption of conformity stays valid only as long as a reference to this European Standard is maintained in the list published in the Official Journal of the European Union. Users of this standard should consult frequently the latest list published in the Official Journal of the European Union.

WARNING 2 — Other Union legislation may be applicable to the product(s) falling within the scope of this standard.

Bibliography

[1] Directive 2014/68/EU of the European Parliament and of the Council of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment

[2] EN 1092-2, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 2: Cast iron flanges*

[3] EN 1092-3, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 3: Copper alloy flanges*

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[5] EN 10253-2:2007, *Butt-welding pipe fittings — Part 2: Non alloy and ferritic alloy steels with specific inspection requirements*

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