

INTERNATIONAL STANDARD

**ISO
5730**

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Stationary shell boilers of welded construction (other than water-tube boilers)

*Chaudières à tubes de fumée de construction soudée (autres que
chaudières aquatubulaires)*



Reference number
ISO 5730:1992(E)

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ISO 5730:1992(E)**Foreword**

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 5730 was prepared by Technical Committee ISO/TC 11, *Boilers and pressure vessels*, Sub-Committee SC 5, *Shell boilers*.

Annexes A, B, C, D, E, F, G, H and J of this International Standard are for information only.

Stationary shell boilers of welded construction (other than water-tube boilers)

Section 1: General

1.1 Scope

1.1.1 This International Standard specifies requirements for both directly fired boilers and waste-heat boilers with a gas-side pressure not exceeding $0,05 \text{ N/mm}^2$ ($0,5 \text{ bar}$)¹⁾, of cylindrical horizontal designs, constructed from carbon or carbon manganese steels by fusion welding and, in the case of directly fired boilers, a design pressure not exceeding 3 N/mm^2 . The boilers covered by this International Standard are intended for land use for providing steam or high-pressure hot water. (Typical examples are shown in figures 1 to 5.) This International Standard does not apply to water-tube boilers, to boilers for railway locomotives, or to marine boilers.

1.1.2 This International Standard applies to the boiler proper, from the feed-water inlet connection to the steam outlet connection and to all other connections, including those required for valves and steam and water fittings. If welded ends are used, the requirements specified herein begin or end at the weld where flanges, if used, would have been fitted.

1.1.3 This International Standard applies to boilers having a capacity of greater than $0,025 \text{ m}^3$, a pressure greater than $0,1 \text{ N/mm}^2$ and a water temperature in excess of 120°C .

1.1.4 Air preheaters, mechanical stokers, gas- or oil-burning equipment, forced- or induced-draught equipment or other accessories which may be required by the purchaser are not considered as parts

of a boiler for the purposes of this International Standard. Superheaters and economizers either integral with or separate from the boiler shall be constructed to the requirements of the future International Standard for water-tube boilers.

1.1.5 This International Standard does not cover brickwork setting, insulation or furnace fittings.

1.1.6 This International Standard does not cover rules of construction since they cannot be written in sufficient detail to ensure good workmanship and construction. Each manufacturer is responsible for taking every necessary step to make sure that the quality of workmanship and construction is such as to ensure compliance with good engineering practice.

1.1.7 Informative references are given in annex J.

1.2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

1) $1 \text{ N/mm}^2 = 1 \text{ MN/m}^2 = 1 \text{ MPa}$

$1 \text{ bar} = 10^5 \text{ N/m}^2 = 10^5 \text{ Pa}$

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ISO 148:1983, *Steel — Charpy impact test (V-notch)*.

ISO 1027:1983, *Radiographic image quality indicators for non-destructive testing — Principles and identification*.

ISO 1106-1:1984, *Recommended practice for radiographic examination of fusion welded joints — Part 1: Fusion welded butt joints in steel plates up to 50 mm thick*.

ISO 1106-2:1985, *Recommended practice for radiographic examination of fusion welded joints — Part 2: Fusion welded butt joints in steel plates thicker than 50 mm and up to and including 200 mm in thickness*.

ISO 1106-3:1984, *Recommended practice for radiographic examination of fusion welded joints — Part 3: Fusion welded circumferential joints in steel pipes of up to 50 mm wall thickness*.

ISO 2504:1973, *Radiography of welds and viewing conditions for films — Utilization of recommended patterns of image quality indicators (I.Q.I.)*.

ISO 2604-1:1975, *Steel products for pressure purposes — Quality requirements — Part 1: Forgings*.

ISO 2604-2:1975, *Steel products for pressure purposes — Quality requirements — Part 2: Wrought seamless tubes*.

ISO 2604-3:1975, *Steel products for pressure purposes — Quality requirements — Part 3: Electric resistance and induction-welded tubes*.

ISO 2605-1:1976, *Steel products for pressure purposes — Derivation and verification of elevated temperature properties — Part 1: Yield or proof stress of carbon and low alloy steel products*.

ISO 2605-3:1985, *Steel products for pressure purposes — Derivation and verification of elevated temperature properties — Part 3: An alternative procedure for deriving the elevated temperature yield or proof stress properties when data are limited*.

ISO 4126-1:1991, *Safety valves — Part 1: General requirements*.

ISO 5579:1985, *Non-destructive testing — Radiographic examination of metallic materials by X- and gamma rays — Basic rules*.

ISO 5580:1985, *Non-destructive testing — Industrial radiographic illuminators — Minimum requirements*.

ISO 6947:1990, *Welds — Working positions — Definitions of angles of slope and rotation*.

ISO 9328-1:1991, *Steel plates and strips for pressure purposes — Technical delivery conditions — Part 1: General requirements*.

ISO 9328-2:1991, *Steel plates and strips for pressure purposes — Technical delivery conditions — Part 2: Unalloyed and low-alloyed steels with specified room temperature and elevated temperature properties*.

ISO 10474:1991, *Steel and steel products — Inspection documents*.

1.3 Definitions

For the purposes of this International Standard, the following definitions apply. Throughout this International Standard additional definitions have been included as necessitated by the specific text concerned.

1.3.1 purchaser: Individual or organization who buys the completed boiler from the manufacturer.

1.3.2 designer: Individual or organization who assumes the sole responsibility for the design of the boiler. He/it determines the shape, dimensions and thickness of the boiler, selects the materials and details the methods of construction and testing.

1.3.3 manufacturer: Individual or organization who fabricates or assumes responsibility for the fabrication of the boiler or any component thereof.

1.3.4 material supplier: Individual or organization not being a material producer, who supplies material or prefabricated standardized parts to be used in the construction of the boiler or any component thereof.

1.3.5 producer of the supplied construction material; material producer: Individual or organization who produces materials for the fabrication of the boiler, components or prefabricated standardized parts.

1.3.6 regulating authority: Authority in the country of installation which is legally charged with the enforcement of that country's requirements of the law and regulations relating to boilers.

1.3.7 inspecting authority: That independent body or association, acting on behalf of

a) the purchaser or owner and/or

b) the regulating authority,

which performs the check that the design, materials and construction requirements comply with this International Standard.

1.3.8 inspector: Person employed and trained by an inspecting authority to carry out the functions of that inspecting authority as indicated in 1.3.7 (see also 6.1).

1.3.9 national standard: Specific standard which has proved to be satisfactory in use, which is acceptable to the regulating authority, which is a specification or rule prepared by a national standards body or similar authority, and which includes rules prescribed by government authorities and having the force of law.

1.4 Symbols

For the purposes of this International Standard, the general terminology and symbols indicated below shall apply. Throughout this International 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 of section 3 (Design of the parts under pressure) the same additional symbol is used in different formulae to represent different terms. However, in all such cases, the special meaning of each symbol is indicated for each formula.

a	Dimensions indicated in figures 14, 16 to 18, 43 and 47.	mm
a_i	Inner major axis of compensating plate.	mm
a_o	Outer major axis of compensating plate.	mm
A	Effective radiant heating surface (see figures 1 to 5).	m ²
A_t	Cross-sectional area effective as compensation without consideration of allowances.	mm ²
A_{tb}	Cross-sectional area of branch effective as compensation.	mm ²
A_{tp}	Cross-sectional area of reinforcing pad effective as compensation.	mm ²
A_{ts}	Cross-sectional area of main body effective as compensation.	mm ²
A_p	Pressure-loaded area without consideration of allowances.	mm ²
A_{pb}	Pressure-loaded area relative to branch.	mm ²
A_{ps}	Pressure-loaded area relative to main body.	mm ²
b	Dimensions indicated in figures 14, 16 to 19, 34, 35, 43, 47 and B.1.	mm
b_1	Minor axis of manhole.	mm
b_i	Inner minor axis of compensating plate.	mm
b_o	Outer minor axis of compensating plate.	mm
B_1	Distance from end plate of shell to centre of saddle.	mm
B_2	Width of saddle top plate.	mm
c	Corrosion allowance.	mm
C	Shape factor (figure 7).	
C_1	Constant depending on method of support as given in 3.14.2.4.	
C_2	Effective length of nozzle as given in 3.10.2 and figure 10.	mm
C_3	Factor for the calculation of stress at saddle support.	
d	Diameter of tube hole.	mm
d_i	Internal diameter.	mm
d_{ib}	Internal diameter of branch.	mm
d_{ip}	Diameter of inner periphery of circular pad or compensating plate.	mm
d_{is}	Internal diameter of main body (cylindrical shell, spherical shell or dished head).	mm
d_g	Depth of welded-on girder stay.	mm
d_m	Mean diameter.	mm
d_o	Outside diameter.	mm
d_{ob}	Outside diameter of branch.	mm
d_{op}	Diameter of outer periphery of circular pad or compensating plate.	mm
d_{os}	Outside diameter of main body.	mm

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d_s	Diameter of stay.	mm
D_b	Gasket mean diameter.	mm
D_L	Bolt circle diameter.	mm
e	Minimum wall thickness.	mm
e_{cb}	Calculated wall thickness of branch or standpipe.	mm
e_{cf}	Calculated wall thickness of furnace.	mm
e_{cp}	Calculated wall thickness of end plate.	mm
e_{cs}	Calculated wall thickness of main body (cylindrical or spherical shell or dished head).	mm
e_{ct}	Calculated wall thickness of tube.	mm
e_g	Thickness of gusset stay.	mm
e_{rb}	Actual wall thickness of branch or standpipe minus allowances for corrosion and minus tolerances.	mm
e_{rep}	Actual wall thickness of flat end plate.	mm
e_{rf}	Actual wall thickness of furnace.	mm
e_{rp}	Effective wall thickness of reinforcing pad.	mm
e_{rs}	Actual wall thickness of main body (cylindrical or spherical shell or dished head) minus allowances for corrosion and minus tolerances.	mm
e_t	Ordered tube thickness.	mm
E	Young's modulus of elasticity at design temperature.	N/mm ²
f	Nominal design stress.	N/mm ²
f_a	Existing mean stress.	N/mm ²
$f_{a\varphi}$	Existing mean stress between the centres of two openings.	N/mm ²
f_b	Allowable stress for the branch material.	N/mm ²
f_c	Combined stress at supports.	N/mm ²
f_p	Allowable stress for the reinforcing plate material.	N/mm ²
f_s	Allowable stress for the material of the main body.	N/mm ²
F	Calculation heat flux.	W/m ²
g, g_1	Clear height as shown in figure 13.	mm
G	Gas mass flow rate in first pass tubes.	kg/(m ² ·s)
h	Minimum width of gusset stay.	mm
h_c	Depth of curvature of dished head.	mm
h_t	Height of manhole frame.	mm
h_s	Length of skirt of dished head.	mm
H	Net heat input (burner heat release rate based on the net calorific value of the fuel plus any preheat).	W
I_1	Second moment of area of one complete furnace corrugation about its neutral axis excluding corrosion allowance.	mm ⁴
I_2	Second moment of area of stiffeners.	mm ⁴
K	Thermal conductivity.	(W·mm)/(m ² ·K)
l_{rb}	Effective length of branch contributing to reinforcement.	mm
l_{rbi}	Effective length of inward projection of set-through branch contributing to reinforcement.	mm
l_{rp}	Effective width of reinforcing pad.	mm
l_{rs}	Effective length of main body contributing to reinforcement.	mm
L	Distance between two effective points of furnace support.	mm

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 there is no access opening, half the maximum distance between the centre-lines of the stays.	mm
L_2	Distance between the rear plate of the reversal chamber and the boiler back end plate.	mm
L_b	Length of boiler between end plates.	mm
L_1	Length of leg of fillet weld around inner periphery of pad or compensating plate.	mm
L_g	Length of welded-on girders.	mm
L_h	Heated length of furnace.	mm
L_o	Length of leg of fillet weld around outer periphery of pad or compensating plate.	mm
L_s	Length of shell between end plates.	mm
L_1	Mean pitch of adjacent tubes.	mm
p	Calculation pressure.	N/mm ²
p_b	Centre-to-centre distance of adjacent openings, referred to wall centre, without allowances.	mm
$p_{b\varphi}$	Centre-to-centre distance of adjacent openings, offset by angle φ , referred to wall centre without allowances.	mm
p_c	Pitch of corrugations.	mm
p_t	Hydrostatic test pressure.	N/mm ²
Q	Force on saddle.	N
r_{ik}	Inside radius of knuckle of dished head.	mm
r_{is}	Inside radius of curvature of dished head or spherical shell.	mm
r_{ms}	Mean radius of shell.	mm
r_{ok}	Outside radius of knuckle of dished head.	mm
r_{os}	Outside radius of curvature of dished head or spherical shell.	mm
R_m	Minimum tensile strength for the grade of material concerned at room temperature.	N/mm ²
$R_{p0,2}$	Minimum value of yield point (0,2 % proof stress) for the grade of material concerned at temperature t .	N/mm ²
S	Pitch of welded-on girders.	mm
S_1	Factor of safety.	
S_2	Factor of safety.	
S_o	Original cross-sectional area of test piece subjected to a tensile test.	mm ²
t	Calculation temperature.	°C
t_m	Maximum metal temperature.	°C
t_s	Saturation temperature corresponding to design pressure.	°C
u	Out-of-roundness, or ovality.	%
v	Weld factor.	
w	Depth of corrugations.	mm
W	Force exerted by the pressure on the end plate in the zone assumed to be supported by the gusset.	N
x	Stress reduction factor.	
X_2	Cross-sectional area of longitudinal section of furnace wall of length equal to one pitch and thickness $e_H - c$.	mm ²
y	Factor determined from figure 18 using the ratio b/a .	
φ	Angle of connecting lines between the centres of two openings relative to the axis of the main body.	degree

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ψ	Angle of inclination of branch relative to the normal to the circumferential line of the main body.	degree
θ	Angle subtended by the saddle.	degree

1.5 Information to be supplied by the purchaser and the manufacturer

1.5.1 Information to be supplied by the purchaser

The purchaser shall disclose to the manufacturer at the time of the enquiry

- a) the name of the inspecting authority representing the purchaser,
- b) the conditions under which the boiler will be required to operate (see 3.1.1 and annex A), and
- c) any special statutory or other regulations with which the boiler is required to comply (e.g. boiler laws in countries other than that of manufacture).

See annex A for further information.

1.5.2 Information to be supplied by the manufacturer

Prior to the construction of a boiler or a series of boilers, the manufacturer of the boiler(s) shall supply the inspecting authority with a list of materials, calculations for major design details and fully dimensioned sectional drawings showing in full detail the construction of all the pressure parts of the boiler, including weld details (for further information, see annex B). The manufacturer shall also furnish certificates and documentation in accordance with 7.1.

The boiler manufacturer shall supply the purchaser with operating instructions appropriate to the equipment supplied. Where alternative methods of manufacture or testing are permitted by this International Standard, the manufacturer shall disclose to the purchaser or the inspecting authority, or both, the method selected by him before putting the work in hand.

Section 2: Materials

2.1 Introduction

The provisions of section 2 cover

- a) plates,
- b) wrought seamless, electric resistance welded and induction welded tubes,
- c) forgings, and
- d) weld metal

of carbon and carbon manganese steels for pressure parts of shell boilers covered by this International Standard.

NOTE 1 The word "tube" refers also to "pipe".

2.2 General

2.2.1 Basic materials

2.2.1.1 Shell boilers shall be constructed from steel products selected in accordance with a), b) or c) as follows:

- a) steel products of the types listed in table 1, manufactured in accordance with ISO 2604-1, ISO 2604-2, ISO 2604-3 or ISO 9328-2, and which comply in all respects with the minimum requirements of this International standard;
- b) steel products of the types listed in table 1, manufactured in accordance with national standards or specifications, provided that these comply in all respects with the appropriate part of ISO 2604 or ISO 9328 for the steel type concerned and with the minimum requirements of this section;
- c) steel products of the types listed in table 1, manufactured in accordance with national standards or specifications which do not comply in all respects with the requirements of the appropriate part of ISO 2604 or ISO 9328, provided that these comply in all respects with the minimum requirements of this section and are agreed between the interested parties.²⁾

Subsequent references to ISO 2604 or ISO 9328 throughout this section shall be considered also to

2) The circumstances of each instance, including any relevant contractual or regulatory requirements, will determine which of the interested parties (defined in section 1) are concerned in the agreements referred to in section 2.

include such non-ISO specifications referred to under b) and c) above.

2.2.1.2 Furnaces with a mean diameter not exceeding 1 400 mm shall be made either from plate to ISO 9328-2 steel types PH 265 or PH 290, or from hot-finished seamless steel tube to ISO 2604-2, TS 9H.

Furnaces with a mean diameter exceeding 1 400 mm shall be made from steel plate with a minimum percentage elongation of 24 % determined with reference to a gauge length of $5,65\sqrt{S_0}$.

2.2.1.3 Cylindrical shells shall be manufactured from plate material only. Plate cut from strip shall be permitted provided that all the requirements for plate in this section are complied with.

2.2.2 Weld metal

In the absence of International Standards for the composition and properties of weld metal suitable for use with the various grades of steels covered in 2.2.1, the welding process and weld metal (electrodes, filler wire, etc.) to be used shall be agreed between the parties concerned as suitable for the parent metals concerned and for the design conditions of the vessel. This agreement shall take account of successful past service and/or test results on the weld metal. Where relevant national standards or specifications exist, the weld materials shall comply with these. The mechanical properties of the weld metal shall in all cases meet the requirements of 5.2.2 and 5.10 and also such other requirements as may be agreed between the parties.

2.3 Manufacture of the steel

2.3.1 Steel-making process

The steel shall be produced by the open-hearth, electric or one of the basic oxygen processes, or by a combination of these processes. Other processes may be used by agreement between the interested parties, who shall be informed of the steel-making process used.

2.3.2 De-oxidation

Rimming steels and semi-killed steels shall not be permitted.

2.4 Forgings

In the case of forgings, the steel shall be forged by hammering, drop forging, pressing, ring rolling, extruding, upsetting, or by any combination of these processes. Forging reduction shall be carried out under a tool of sufficient power and to an extent that will ensure ample working of the metal throughout its section. The forgings shall be brought, as nearly as practicable, to the finished shape and size by hot working.

2.5 Heat treatment

2.5.1 Plates and forgings shall be supplied in a heat-treated condition appropriate to the steel type as specified in the applicable International Standard, unless otherwise agreed by the interested parties. For plates, the application of controlled temperatures during or after rolling may take the place of normalizing, provided that this is permitted for the steel type concerned in the International material Standard, that the specified material properties would be complied with after an additional normalizing treatment, and that no contrary agreements have been made between the interested parties at the time of enquiry and order.

2.5.2 Unless otherwise agreed between the interested parties, seamless and welded tubes shall be supplied in one of the conditions appropriate to the steel type as specified in the applicable International Standard.

2.6 Chemical composition

2.6.1 For steels intended for welding, the upper limit of the carbon range (in the cast analysis) should, in general, not exceed 0,23 %. For steels with a carbon content higher than 0,23 % and up to a maximum of 0,25 %, which are intended for welding, welding procedures should be specially agreed between the parties concerned at the time of enquiry and order (see also 5.1.1 and 5.8.1).

2.6.2 In the cast analysis, phosphorous and sulfur contents shall not exceed 0,035 % and 0,030 % respectively.

2.6.3 If the interested parties consider that the level of particular residual elements, not already specified in the applicable International Standard, is important in relation to the mechanical and technological properties of the steel, an upper limit of the residual elements should be agreed between the parties concerned and shall be specified in the order.

2.7 Mechanical properties

2.7.1 Values for the mechanical properties used in the design of shell boilers shall be as specified in the applicable International Standard. The values specified shall cover the appropriate range of service temperature.

2.7.2 For all products the mechanical properties at room temperature shall be specified. These are the tensile strength range, the minimum specified yield strength, the minimum percentage elongation after fracture, and for tubes the test category and, where specified, the minimum impact test value (average of three tests).

2.7.2.1 The specified minimum tensile strength shall be not less than that given in table 1 for the corresponding products; the maximum tensile strength shall not exceed the minimum tensile strength by more than 120 N/mm² and shall in no case be higher than 580 N/mm².

2.7.2.2 The specified minimum percentage elongation after fracture referred to a gauge length of $5,65\sqrt{S_0}$ and, where specified, the minimum requirements for the impact, flattening, bend, drift expanding or flanging tests shall be appropriate to the type of steel and comparable to the value given in the International Standard [see 2.2.1.1 a)] for steels with a similar lower limit of the specified tensile strength range.

A minimum impact energy value of 27 J shall be obtained when testing transverse V-notch test pieces.

2.7.3 For all products the minimum 0,2 % proof stress at elevated temperature ($R_{p0,2}$) shall be specified.

2.7.3.1 When a sufficient amount of data is available, the minimum elevated-temperature proof stress values shall be derived in accordance with ISO 2605-1.

2.7.3.2 When only limited amounts of data are available, the minimum elevated-temperature proof stress values shall be derived in accordance with ISO 2605-3.

2.7.3.3 Minimum elevated-temperature proof stress values not derived according to 2.7.3.1 or 2.7.3.2 may also be used provided that

- a) they are adopted for an International Standard for products for pressure purposes, or
- b) they are listed in a national standard and are verified, where necessary, in accordance with 2.8.

2.8 Verification procedures

2.8.1 The compliance of the steel with the specifications for its chemical composition shall be verified by a cast analysis.

2.8.2 The specified room temperature properties shall be verified by acceptance tests.

For the verification of the yield strength, the upper yield stress R_{eH} or the 0,5 % total elongation proof stress $R_{t0,5}$ shall be measured, and the material specification is complied with in this respect if either value satisfies the specified value of yield strength.

2.8.3 The minimum elevated-temperature proof stress values shall be verified, where necessary, by

- a) elevated-temperature acceptance testing in accordance with the appropriate part of ISO 2604, or
- b) the procedure given in ISO 2605-1:1976, clause 3, or
- c) a verification procedure acknowledged by the interested parties as equivalent to the verification procedure given in ISO 2605-1:1976, clause 3.

2.8.4 Where steel products are manufactured and supplied in accordance with ISO 2604, ISO 9328-2 or an equivalent national standard giving elevated-temperature proof stress values which do not exceed the values specified in ISO 2604 or ISO 9328-2 for a comparable steel, then the proof stress values specified in ISO 2604, ISO 9328-2 or in the equivalent national standard as appropriate, may be used for design purposes without verification.

Elevated-temperature acceptance testing in accordance with 2.8.3 a) shall be carried out only if so specified at the time the steel is ordered.

2.8.5 Where steel products are manufactured and supplied in accordance with a national standard which gives elevated-temperature proof stress values greater than the values specified in ISO 2604 or ISO 9328-2 for a comparable steel, then the values shall be verified in accordance with 2.8.3.

2.9 General rules for carrying out acceptance tests

Acceptance tests shall be carried out in accordance with the general rules given in ISO 2604-1, ISO 2604-2, ISO 2604-3 or ISO 9328-1 as appropriate.

2.10 Number, selection and preparation of samples and test pieces

The number, selection and preparation of samples and test pieces shall be in accordance with the appropriate part of ISO 2604 or with ISO 9328-1 except where otherwise stated in the following subclauses.

2.10.1 The minimum test requirements for tubes are

- visual inspection,
- hydraulic test,
- tensile test, and
- flattening or bend test.

Additionally, when tubes are to be expanded or swaged, a drift expanding or flanging test shall be carried out.

2.10.2 Impact tests on tubes are not required.

2.10.3 Every plate, tube and forging shall be inspected visually and appropriate checks shall be made for compliance with the dimensional tolerances.

2.11 Method of testing

2.11.1 The tests shall be made in accordance with the relevant International Standards. If no appropriate International Standard exists, the methods to be used shall be agreed upon between the interested parties and specified at the time of enquiry and order.

2.11.2 For elevated-temperature tests, the testing temperature shall be agreed upon between the interested parties at the time of enquiry and order.

2.12 Retests

Retests shall be carried out in accordance with the corresponding specifications in the appropriate parts of ISO 2604 or in ISO 9328-1.

2.13 Documents

2.13.1 For all steel products, the type of inspection certificate or inspection report (see ISO 10474:1991, section 3) shall be agreed by the interested parties at the time of enquiry and order.

NOTE 2 Use may be made of the model form given in annex E.

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2.13.2 For steels with a specified minimum tensile strength of less than 460 N/mm², it may be satisfactory to select inspection certificate 3.1.B in accordance with ISO 10474:1991, namely that inspection and testing shall be carried out by the qualified department of the steel manufacturer's works.

2.13.3 For steels with a specified minimum tensile strength equal to or greater than 460 N/mm², inspection report 3.2 in accordance with ISO 10474:1991 shall be selected except that the in-

spection and testing shall be carried out in the presence of the inspecting authority.

2.14 Marking

The products shall be marked in accordance with the requirements of ISO 2604-1, ISO 2604-2, ISO 2604-3 or ISO 9328-1 as appropriate.

Table 1 — Internationally standardized steel types for shell boilers

Tensile strength R_m ¹⁾	Steel types			
	Plates	Tubes seamless	Tubes electric resistance or induction welded	Forgings
	ISO 9328-2 ²⁾	ISO 2604-2 ²⁾	ISO 2604-3 ²⁾	ISO 2604-1 ²⁾
320 to 440	—	TS ³⁾	—	—
360 to 480	—	TS 5	TW 5	—
410 to 530	PH 265	TS 9H	TW 9H	F8, F9
460 to 580	PH 290	—	—	—
1) The tensile strength values given in this table are for classification purposes only. The governing specifications are those given in the appropriate product standard. 2) Or in accordance with 2.2.1.1 b) or c). 3) TS 2 material may be used only for smoke tubes.				

Section 3: Design of the parts under pressure

3.1 General

3.1.1 Boilers

The requirements in this International Standard apply to boilers constructed throughout under the conditions specified herein and which are to be operated under normal operating conditions, with good feed-water and boiler water in accordance with annex D, and under adequate supervision. Where risk of abnormal working conditions, such as severe cyclic service, is foreseen, the design shall be given special consideration and shall be made known to the inspecting authority.

3.1.2 Generators

For hot-water generators and superhot-water generators, the difference between the starting temperature (outlet) and the return temperature (inlet) should not exceed 30 °C. If the difference between the flow and return temperature is greater than 30 °C, either internal or external mixing devices shall be used to limit the differential temperature within the boiler to 30 °C.

The difference between the saturation temperature corresponding to the total gauge pressure and the inlet temperature shall not exceed 80 °C. For differences over 60 °C, the breathing spaces given in 3.14.1 shall be increased by 50 %, and the maximum net heat input shall be reduced by at least 20 % to allow for the reduction of the cold-water cooling conditions and the increase in heat input due to the large temperature differences, unless other arrangements are used to the same end.

3.1.3 Design of principal welded seams

3.1.3.1 The types of weld employed in the design of the boiler shall be in accordance with 5.3.2.5. Welds which are subjected to non-destructive testing in accordance with the requirements of this International Standard shall be designed so that the required tests can be properly carried out.

3.1.3.2 The value of the weld factor v used in the calculation for the shell thickness shall be either 0,8 or 1 depending on the extent of testing to be carried out (see 3.7.1, 5.5.5.1 and 5.8.17.1).

3.2 Design pressure

The design pressure is the maximum allowable set pressure of the safety valves.

3.3 Calculation pressure

The calculation pressure shall be taken as the design pressure plus the hydrostatic head where this exceeds 3 % of the design pressure.

3.4 Calculation temperature

The calculation temperature shall be the mean metal temperature and shall be determined as specified in a) to e) below. In no case shall it be less than 150 °C.

- a) For shells, drums and other components not designed for heat transfer purposes, the calculation temperature shall be not less than the saturation temperature corresponding to the design pressure.
- b) For smoke tubes, the calculation temperature shall be determined in accordance with the following equations:

$$t = (t_s + 2e) \quad \dots (3.1)$$

or

$$t = (t_s + 25) \quad \dots (3.2)$$

whichever is the greater, with a minimum of 250 °C.

- c) The calculation temperature for plain areas of plate not swept by flame, or for tube nest areas where the gas entry temperature is not greater than 800 °C, shall be determined in accordance with the equation

$$t = (t_s + 50) \quad \dots (3.3)$$

or equation (3.1):

$$t = (t_s + 2e)$$

whichever is the greater, with a minimum of 250 °C. Combustion is to be completed in the furnace.

- d) For tube plates subject to gas entry temperatures exceeding 800 °C in fired boilers using fossil fuels, including natural gas, the calculation temperature shall be determined in accordance with annex C, using the true gas entry temperature t_G determined from the following equation with a minimum of 250 °C:

$$t_G = 51 \left(\frac{H}{A} \right)^{0,25} \quad \dots (3.4)$$

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For fuels where the true gas entry temperature is higher than that obtained with natural gas, and for waste-heat boilers, the calculation temperature shall be determined in accordance with annex C.

The maximum metal temperature as determined in accordance with annex C shall not exceed 420 °C.

These requirements are based on good contact between smoke tubes and tube sheet. Where this cannot be ensured, the following limitations apply [see figure 32 f)]:

- 1) the depth of the connecting weld between smoke tubes and tube sheet shall be greater than or equal to the wall thickness of the smoke tube plus 2 mm;
 - 2) the length of the gap, measured from the root of the weld, shall be less than or equal to four times the wall thickness of the smoke tube.
- e) The calculation temperature for furnaces shall be determined in accordance with the following equation

$$t = t_s + 4e + 15 \quad \dots (3.5)$$

with a minimum of 250 °C.

Equation (3.5) gives the calculated temperature for the purpose of determining the nominal design stress and does not represent the maximum metal temperature.

3.5 Furnaces

In order to ensure safe burner/boiler combinations, the net heat input for a given furnace tube inside diameter shall not exceed the value given in figure 6. On/off type burners (100 % to 0 %) shall not be used for heat inputs exceeding 1 MW per furnace.

Deviation from the values given in figure 6, and net heat input values greater than 11,5 MW, are permitted by agreement between the interested parties: mainly the boiler manufacturer, the burner manufacturer and the inspecting authority.

The agreement, and all conditions on which it is based, shall be stated in the boiler certificate and made known to the user.

When boilers are designed with net heat input greater than 11,5 MW, special consideration shall be given in the determination of the calculated temperature, maximum heat flux, breathing spaces and possible smoke tube support.

The length of the refractory should not be greater than 400 mm measured from the end of the atomizer.

3.6 Nominal design stress

The nominal design stress f shall be the lower of the values obtained from the following ratios:

$$\frac{R_{p0,2}}{1,5} \text{ and } \frac{R_m}{2,4}$$

NOTE 3 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 section 3 will maintain the actual maximum stresses within acceptable limits for the type of loading considered.

3.7 Cylindrical shells under internal pressure

3.7.1 Minimum thickness for pressure loading only

Subject to the conditions specified in 3.7.2, the minimum thickness e for pressure loading only shall be calculated from the following equations:

$$e = e_{cs} + c \quad \dots (3.6)$$

where

$$c = 0,75 \text{ mm (corrosion allowance);}$$

$$e_{cs} = \frac{pd_o}{2fv + p} \quad \dots (3.7)$$

When calculating e , any negative thickness tolerances shall be taken into account.

For boilers having an outside shell diameter greater than 1000 mm the shell wall shall not be less than 6 mm thick.

For boilers having an outside shell diameter equal to or less than 1000 mm the shell wall shall not be less than 4 mm or $(e_{cs} + c)$ mm thick, whichever is the greater.

The value of the weld factor v shall depend on the extent of non-destructive testing of the longitudinal welded seam in accordance with 3.1.3.2 and 5.5.5.1.

3.7.2 Conditions of application of formulae (3.6) and (3.7)

Formulae (3.6) and (3.7) (see 3.7.1) shall apply only if the following conditions are fulfilled.

- a) The ratio of the outside radius to the inside radius does not exceed 1,5.
- b) At the welded seams the mid-thickness lines are an extension of each other within the alignment tolerances specified in 5.8.10.

- c) A cylindrical shell shall conform to the tolerances specified in 4.3.2.

or

$$0,01d_o \leq e_{cs} \leq 0,03d_o$$

$$r_{ik} \geq 0,1d_o$$

$$h_c = 0,18d_o$$

or

$$0,02d_o \leq e_{cs} \leq 0,03d_o$$

$$r_{ik} \geq 0,1d_o$$

$$0,18d_o \leq h_c \leq 0,22d_o$$

The two relationships in b) and the three or five relationships in c) shall be fulfilled simultaneously.

3.8 Unstayed dished heads without openings

3.8.1 Unstayed dished heads under internal pressure

The minimum thickness of unstayed dished heads without openings shall be in accordance with equation (3.6)

$$e = e_{cs} + c$$

where $c = 0,75$ mm (corrosion allowance), and the following equation:

$$e_{cs} = \frac{pd_o C}{2f} \quad \dots (3.8)$$

In addition, the thickness of a torispherical head shall not be less than that given by equation (3.6)

$$e = e_{cs} + c$$

where $c = 0,75$ mm (corrosion allowance), and the following equation:

$$e_{cs} = \frac{pr_{is}}{2f - 0,5p} \quad \dots (3.9)$$

The shape factor C for unstayed dished heads without openings shall be as given in figure 7. However, the limiting conditions given in 3.8.2 shall apply.

3.8.2 Limiting conditions

- a) Hemispherical heads

$$0,005d_o \leq e_{cs} \leq 0,16d_o$$

- b) Ellipsoidal heads

$$0,005d_o \leq e_{cs} \leq 0,08d_o$$

$$h_c \geq 0,18d_o$$

- c) Torispherical heads

$$0,005d_o \leq e_{cs} \leq 0,08d_o$$

$$r_{ik} \geq 0,1d_o$$

$$r_{ik} \geq 2e_{cs}$$

$$r_{is} \leq d_o$$

$$h_c \geq 0,18d_o$$

3.8.3 Unstayed dished heads under external pressure

The calculation pressure p shall be the lower of the values obtained from the following equations:

$$p = \frac{e_{cs} R_{p0,2}}{1,2r_{os}} \quad \dots (3.10)$$

$$p = \frac{0,8E}{9 + 0,006\left(\frac{r_{os}}{e_{cs}}\right)} \times \left(\frac{e_{cs}}{r_{os}}\right)^2 \quad \dots (3.11)$$

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 3.8.1), with or without openings reinforced according to 3.9.

3.9 Design of openings in cylindrical shells, spherical shells and dished heads

3.9.1 General

3.9.1.1 The design methods specified in 3.9.2 to 3.9.4 shall apply to cylindrical shells, spherical shells and dished heads having circular or elliptical openings, where the assumptions and conditions specified in 3.9.1.2 to 3.9.1.9 have been taken into consideration.

Forces/moments caused by loads arising from sources other than internal pressure are not included when calculating reinforcements.

3.9.1.2 Cylindrical shells, spherical shells and dished heads with openings shall be reinforced where necessary. The reinforcement of the main body can be obtained by the following measures:

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- a) by an increased wall thickness of the main body compared with that of the shell without openings [see figures 8 a) and 8 b)];
- b) by set-on welded compensating plates [see figures 8 c) and 8 d)];
- c) by set-in welded pads [see figures 8 e) and 8 f)];
- d) by set-on or set-in welded branches [see figures 8 g) and 8 h)];
- e) by combinations of the above-mentioned measures [see figures 8 i) and 8 j)].

3.9.1.3 The reinforcement areas of the main body with openings cannot be calculated directly but shall be assumed in the first instance. That assumption may be verified by means of the methods laid down. The applied method is derived from formula (3.7) for cylindrical shells and from formula (3.8) for spherical shells and spherical sections of dished heads respectively and leads to relationships between a pressure-loaded area A_p and a stress-loaded cross-sectional area A_t . Under certain circumstances the calculation may need to be repeated using a corrected assumption of the reinforcement area.

3.9.1.4 Where necessary, sufficient reinforcement shall be provided in all planes through the axis of the opening or branch.

3.9.1.5 For cylindrical shells and spherical shells, the ratio between the internal diameters of the opening or branch and of the main body shall fulfill the condition

$$d_{ib}/d_{is} \leq 0,5$$

For dished heads, the openings or branches shall be located within the spherical portion of the head.

3.9.1.6 In the case of elliptical openings, the ratio between the major and the minor axis shall not exceed 1,5. For elliptical openings in cylindrical shells, the axis extending in the direction of the longitudinal axis of the shell shall be taken as the diameter for design purposes. For elliptical openings in spherical shells, the major axis shall be so taken.

3.9.1.7 If the main body and the reinforcement consist of materials with different allowable stresses and if the lowest allowable stress f applies to the material of the main body, that stress governs for the calculation of the entire design, provided that the ductility of the reinforcement is not significantly lower than that of the main body.

3.9.1.8 Set-in or set-on welded branches which are fillet welded without full penetration [see figures 8 n) and 8 o)] shall not be considered as reinforcement and shall be calculated in accordance with 3.9.2.1.

3.9.1.9 Reinforcement of openings by compensating plates is permitted only under the following conditions:

$$\text{diameter ratio } d_{ib}/d_{is} \leq 0,3$$

$$\text{opening temperature } \leq 250 \text{ }^{\circ}\text{C}$$

When any part of a compensating plate with an outer diameter $d_{op} > 200$ mm is situated below the boiler water level, any insulation covering the compensating plate shall be capable of being removed for periodic inspection.

3.9.2 Cylindrical shells, spherical shells and dished heads with isolated openings

3.9.2.1 Reinforcement by increased wall thickness

The reinforcement can be attained by an increased wall thickness of the main body, compared with that without openings. This wall thickness shall exist at least up to a distance

$$l_{rs} = \sqrt{(d_{os} - e_{rs})e_{rs}} \quad \dots (3.12)$$

measured from the edge of the opening, as shown in figures 8 a) and 8 b).

Furthermore the following condition also applies:

$$f_a = p \left(\frac{A_p}{A_t} + \frac{1}{2} \right) \leq f \quad \dots (3.13)$$

3.9.2.2 Reinforcement of isolated openings by compensating plates

Compensating plates shall have close contact with the main body.

The width of compensating plates l_{rp} considered as contributing to the reinforcement, and used to determine A_{tp} in formulae (3.16) and (3.17), shall not exceed l_{rs} :

$$l_{rp} \leq l_{rs} = \sqrt{(d_{os} - e_{rs})e_{rs}} \quad \dots (3.14)$$

according to figures 8 c) and 8 d).

The value of e_{rp} used to determine A_{tp} in formulae (3.16) and (3.17) shall not exceed e_{rs} , and the actual thickness of the compensating plates shall not exceed twice the actual wall thickness of the main body:

$$e_{rp} \leq 2e_{rs} \quad \dots (3.15)$$

The following conditions shall apply when the allowable stress f_s for the material of the main body is equal to or lower than the allowable stress f_p for the material of the compensating plate:

$$f_a = p \left(\frac{A_p}{A_{fs} + 0,7A_{fp}} + \frac{1}{2} \right) \leq f \quad \dots (3.16)$$

Otherwise the following condition applies:

$$\left(f_s - \frac{p}{2} \right) A_{fs} + \left(f_p - \frac{p}{2} \right) 0,7A_{fp} \geq pA_p \quad \dots (3.17)$$

3.9.2.3 Reinforcement of isolated openings by pads

Only pads of the set-in welded type in accordance with figures 8 e) and 8 f) shall be used, and when the following width/thickness relationships occur simultaneously, the boiler shall be stress relieved:

$$l_{rp} > 2,5e_{rs}$$

$$e_{rp} > 3e_{rs}$$

The width of the pads l_{rp} considered as contributing to the reinforcement, and used to determine A_{fp} in formulae (3.18) and (3.19), shall not exceed l_{rs} :

$$l_{rp} \leq l_{rs} = \sqrt{(d_{os} - e_{rs}) e_{rs}}$$

The value of e_{rp} used to determine A_{fp} in formulae (3.18) and (3.19) shall not exceed twice e_{rs} .

The following conditions shall apply when the allowable stress f_s for the material of the main body is equal to or lower than the allowable stress f_p for the material of the pad:

$$f_a = p \left(\frac{A_p}{A_{fs} + A_{fp}} + \frac{1}{2} \right) \leq f \quad \dots (3.18)$$

Otherwise the following condition applies:

$$\left(f_s - \frac{p}{2} \right) A_{fs} + \left(f_p - \frac{p}{2} \right) A_{fp} \geq pA_p \quad \dots (3.19)$$

3.9.2.4 Reinforcement of isolated openings by branches

The wall thickness of branches (nozzles) shall be in excess of the thickness calculated to withstand internal pressure for a length l_b measured from the exterior wall of the main body [see figures 8 g) and 8 h)]. This requirement is independent of any reinforcement provided either by increasing the wall thickness of the main body or by fitting compensating plates [see figures 8 i) and 8 j)].

The maximum value of the branch or nozzle thickness e_{rb} shall be not greater than twice the shell thickness e_{rs} up to a diameter ratio of 0,2:

$$e_{rb} \leq 2e_{rs} \text{ for } \frac{d_{ib}}{d_{is}} \leq 0,2 \quad \dots (3.20)$$

The maximum value of the branch or nozzle thickness e_{rb} shall be not greater than the shell thickness e_{rs} for diameter ratios greater than 0,7:

$$e_{rb} \leq e_{rs} \text{ for } \frac{d_{ib}}{d_{is}} > 0,7 \quad \dots (3.21)$$

Between the limits $d_{ib}/d_{is} = 0,2$ and 0,7, the maximum value of e_{rb} in terms of e_{rs} shall be determined by linear interpolation [see figure 8 k)].

The above-mentioned conditions governing the wall thickness ratio shall not apply to access and inspection openings.

3.9.2.4.1 Isolated openings with vertically arranged branch connections

3.9.2.4.1.1 The following conditions apply for a vertical branch connection without reinforcing plate

$$f_a = p \left(\frac{A_p}{A_{fs} + A_{fb}} + \frac{1}{2} \right) \leq f \quad \dots (3.22)$$

and with reinforcing plate

$$f_a = p \left(\frac{A_p}{A_{fs} + A_{fb} + 0,7A_{fp}} + \frac{1}{2} \right) \leq f \quad \dots (3.23)$$

The areas A_p , A_{fs} , A_{fb} and A_{fp} shall be determined in accordance with figures 8 g) to 8 j), where the lengths contributing to the reinforcement shall be not more than

$$l_{rs} = \sqrt{(d_{os} - e_{rs}) e_{rs}}$$

for the shell, and

$$l_{rb} = 0,8\sqrt{(d_{ob} - e_{rb}) e_{rb}} \quad \dots (3.24)$$

for the branch.

The maximum value to be used in the calculation of the part extending inside, if any, in the case of set-through branches [see figures 8 h) to 8 j)] shall be

$$l_{rbi} = 0,5l_{rb} \quad \dots (3.25)$$

The dimensions of the reinforcing plate to be used in the calculation shall be

$$e_{rp} \leq e_{rs}$$

and

$$l_{rp} \leq l_{rs}$$

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3.9.2.4.1.2 Formulae (3.22) and (3.23) apply only when the allowable stress f_s for the material of the main body is equal to or lower than the allowable stress f_b for the branch and f_p for the reinforcing plate.

3.9.2.4.1.3 When the allowable stress f_b or f_p is lower than the allowable stress f_s of the main body, the following conditions shall apply:

without reinforcing plate

$$\left(f_s - \frac{p}{2}\right)A_{ts} + \left(f_b - \frac{p}{2}\right)A_{tb} \geq pA_p \quad \dots (3.26)$$

and with reinforcing plate

$$\begin{aligned} \left(f_s - \frac{p}{2}\right)A_{ts} + \left(f_b - \frac{p}{2}\right)A_{tb} + \\ + \left(f_p - \frac{p}{2}\right)0,7A_{tp} \geq pA_p \quad \dots (3.27) \end{aligned}$$

The allowable stresses f_b and f_p to be used in formulae (3.26) and (3.27) shall not exceed the value of f_s .

3.9.2.4.1.4 Formed branches in cylindrical shells, spherical shells and dished heads as shown in figures 8 l) and 8 m) may be calculated in accordance with formula (3.22). The areas A_p and A_t to be used therein shall be determined as shown in figures 8 l) and 8 m) where A_t shall be multiplied by 0,9 to compensate for manufacturing inaccuracies. The lengths l_{rs} and l_{rb} contributing to the reinforcement shall be in accordance with formulae (3.12) and (3.24).

3.9.2.4.2 Isolated openings with non-radial branch connections

3.9.2.4.2.1 Cylindrical shells with a non-radial branch

The following items apply to branches on cylindrical shells lying in a plane perpendicular to the longitudinal axis of the shell and having an angle ψ , formed with the normal, which shall not exceed 50°.

The higher stress may occur in the lateral section or in the longitudinal section [see figure 9 a)]. Formula (3.18) or (3.26) shall apply to both cases with the areas A_p and A_{ts} [as shown in the lateral and longitudinal sections of figure 9 a)] to be used in the calculation.

The maximum length considered as contributing to the reinforcement shall be evaluated for the main body in accordance with formula (3.12), and for the branch in accordance with formula (3.24).

3.9.2.4.2.2 Spherical shells with a non-radial branch

Where branches in spherical shells lie in a plane that contains the axis of the branch and the centre of the spherical shell, using the symbols shown in figure 9 b), spherical shells with a branch not radially arranged shall be calculated in accordance with 3.9.2.4.1.

3.9.3 Cylindrical shells, spherical shells and dished heads with multiple openings and branches

3.9.3.1 Cylindrical shells with multiple openings and branches

3.9.3.1.1 Adjacent openings or branches may be regarded as single openings or single branches, if the centre-to-centre distance $p_{b\varphi}$ as shown in figure 9 c) complies with the relation

$$p_{b\varphi} \geq \frac{d_{ob1}}{2} + \frac{d_{ob2}}{2} + 2\sqrt{(d_{os} - e_{rs})e_{rs}} \quad \dots (3.28)$$

3.9.3.1.2 Where $p_{b\varphi}$ is smaller, the following strength consideration

$$\begin{aligned} f_{a\varphi} = p \frac{A_{ps} \frac{1}{2}(1 + \cos^2 \varphi) + A_{pb1} + A_{pb2}}{A_{ts} + A_{tb1} + A_{tb2}} + \\ + \frac{p}{2} \leq f \quad \dots (3.29) \end{aligned}$$

applies in addition to 3.9.2.4.1.1 to 3.9.2.4.1.3 for the cross-section extending through the adjacent openings or branches at the angle φ with the longitudinal axis of the cylindrical shell in accordance with figure 9 c).

3.9.3.1.3 Where the cylindrical shell, branch and reinforcement consist of materials having different allowable stresses and where the allowable stress of the branch is less than that of the cylindrical shell, the following applies in accordance with figure 9 c):

$$\begin{aligned} \left(f_s - \frac{p}{2}\right)A_{ts} + \left(f_{b1} - \frac{p}{2}\right)A_{tb1} + \left(f_{b2} - \frac{p}{2}\right)A_{tb2} \\ \geq \frac{p}{2} [A_{ps}(1 + \cos^2 \varphi) + 2A_{pb1} + 2A_{pb2}] \quad \dots (3.30) \end{aligned}$$

Where the allowable stress of the material of the cylindrical shell is less than that of the material of the branches, the procedure to be followed shall comply with the appropriate requirements in 3.9.2.4.1.2.

3.9.3.1.4 For adjacent openings or branches with identical diameter, made of materials with identical allowable stress and with smaller centre-to-centre distances $p_{b\varphi}$ than that obtained from formula (3.28),

the following will result according to figure 9 c) at $A_{pb1} = A_{pb2}$ and $A_{fb1} = A_{fb2}$:

$$f_{a\varphi} = p \frac{A_{ps} \frac{1}{2} (1 + \cos^2 \varphi) + 2A_{pb1}}{A_{fs} + 2A_{fb1}} + \frac{p}{2} \leq f \quad \dots (3.31)$$

Where materials with different allowable stress are used, the procedure to be followed shall be governed by the appropriate requirements given in 3.9.3.1.3 for the use of formula (3.30).

3.9.3.1.5 For groups of holes, the strength consideration shall be conducted for the ligaments extending in longitudinal, circumferential and diagonal directions.

3.9.3.1.6 The requirements of 3.9.3.1.1 to 3.9.3.1.5 shall be permitted to be used for adjacent branches not radially arranged.

3.9.3.2 Spherical shells and dished heads with multiple openings and branches

Adjacent openings or branches may be treated as an isolated opening or an isolated branch, if the length of the arc p_b as per figure 9 d) complies with the relation

$$p_b \geq \left\{ \arcsin \left[\frac{(d_{ob1}/2) - e_{rb1}}{r_{os} - (e_{rs}/2)} \right] + \arcsin \left[\frac{(d_{ob2}/2) - e_{rb2}}{r_{os} - (e_{rs}/2)} \right] \right\} \times \left(r_{os} - \frac{e_{rs}}{2} \right) + 2\sqrt{(2r_{os} - e_{rs}) e_{rs}} \quad \dots (3.32)$$

where the argument of arcsin is in radians.

Where p_b does not comply with formula (3.32), the strength calculation shall be carried out as follows:

$$f_a = p \left(\frac{A_p}{A_{fs} + A_{fb1} + A_{fb2}} + \frac{1}{2} \right) \leq f \quad \dots (3.33)$$

When the branch material has a higher allowable stress than the material of the spherical shell or dished head, then the appropriate relationships in 3.9.2.4.1.2 shall apply.

If the allowable stress of the branches is lower than that of the dished head or the spherical shell, then the following relationship shall apply:

$$\left(f_s - \frac{p}{2} \right) A_{fs} + \left(f_{b1} - \frac{p}{2} \right) A_{fb1} + \left(f_{b2} - \frac{p}{2} \right) A_{fb2} \geq p A_p \quad \dots (3.34)$$

3.9.4 Design of large isolated openings in headers or tubes with vertical branches or nozzles secured by welding

3.9.4.1 These requirements apply to openings for branches or nozzles in headers or tubes with the following relationship:

$$0,5 < d_{ib}/d_{is} \leq 1$$

The relationships between the ratios e_{rb}/e_{rs} and d_{ib}/d_{is} shall be in accordance with the requirements of 3.9.2.4, and formulae (3.20) and (3.21) as appropriate.

3.9.4.2 The rules for calculation given in 3.9.2.4.1.1 shall be applied where appropriate, provided that the following additional condition is satisfied in the cross-section perpendicular to the axis of the main body (header or tube) in the transition zone of the main body and branch:

$$\frac{p}{1,5} \left(\frac{d_{is} + e_{rs}}{2e_{rs}} + 0,2 \frac{d_{ib} + e_{rb}}{e_{rb}} \times \sqrt{\frac{d_{is} + e_{rs}}{e_{rs}}} \right) \leq f \quad \dots (3.35)$$

Where the main body and the branch are made from materials having different allowable stresses, the lowest value of f shall be used.

3.10 Design of isolated openings in shell boiler flat end plates

3.10.1 Unreinforced openings

The maximum diameter of an unreinforced opening in a flat end plate shall be determined from the following equation:

$$d_{max} = 8e_{rep} \left(1,5 \frac{e_{rep}^2}{e_{cp}^2} - 1 \right) \quad \dots (3.36)$$

3.10.2 Branch openings

Reinforcement for 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 10. The branch thickness shall be increased where required. Compensation shall be considered adequate when the

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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 (3.43) 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 as follows.

- a) For that part of the branch which projects outside the boiler, calculate the full sectional area of the branch up to a distance C_2 from the actual outer surface of the flat end plate and deduct from it the sectional area which the branch would have within the same distance if its thickness were calculated in accordance with formulae (3.6) and (3.7), taking $\nu = 1$.
- b) Add to it the full sectional area of that part of the branch which projects inside the boiler (if any) up to a distance C_2 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 (3.43) for the part of the end plate under consideration by the length D .
- e) Add to it the area of the compensating plate (if any) within the limits of reinforcement shown in figure 10.

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 of sufficient size to transmit the full strength of the reinforcing area and all other loadings to which they may be subjected.

3.10.3 Manholes, headholes and handholes

When elliptical manholes, headholes or handholes are located in flat end plates the openings shall be compensated by flanging the edge of the opening or by the provision of a stiffening ring (see figure 11). The method given in 3.10.2 for calculating the required area of reinforcement shall be used where applicable except that the width of the flange or 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 (3.43) for the part of the end plate under consideration.

The full width of the flange or stiffening ring may be used when calculating area Y .

3.11 Fillet welds attaching compensating plates to shells under internal pressure

The sizes L_1 of the inner fillet welds by which compensating plates are attached to shell plates (see figure 12) shall comply with the following relation-ship:

$$L_1 \geq 0,7e_{rp} \quad \dots (3.37)$$

The sizes L_o of the outer peripheral fillet welds by which compensating plates (see figure 12) are attached to shell plates shall be determined from the following equation, but shall in no case be less than the size of the inner fillet weld:

$$L_o = \frac{d_{ip}(2e_{rs} - L_1)}{d_{op}} \quad \dots (3.38)$$

For elliptical compensating plates

$$d_{op} = \frac{a_o + b_o}{2} \quad \dots (3.39)$$

$$d_{ip} = \frac{a_i + b_i}{2} \quad \dots (3.40)$$

3.12 Minimum thickness of nozzles and branch connections

The thickness of nozzles and branches shall be in accordance with 3.15.2, but the thickness shall be not less than given by the following equation:

$$e = (0,015d_{ob} + 3,2) \geq 4 \quad \dots (3.41)$$

3.13 Access and inspection openings

3.13.1 General requirements

3.13.1.1 All boilers shall be provided with openings adequate in size and number to allow access for fabrication, cleaning and internal inspection (see the guidelines in 3.13.5.1). The dimensions of the openings shall be in accordance with 3.13.2 to 3.13.4.

3.13.1.2 Boilers with a shell diameter d_o of 1400 mm or greater shall be designed to permit entry of a person and shall be provided with a manhole for this purpose.

Boilers with a shell diameter d_o less than 1 400 mm, which are capable of being entered by a person, shall be provided with a manhole. Boilers with a shell diameter between 800 mm and 1 400 mm shall be provided with a headhole as a minimum requirement.

3.13.1.3 The number, size and location of access and inspection openings will vary according to the boiler design. The following guidelines are intended to ensure that a good representative visual examination of the welded seams is possible.

3.13.1.4 Detachable ends or covers may replace all the other examination holes if, by their dimensions and position, a general view of the interior is provided which is at least equivalent to that obtained by the examination holes which otherwise would be required.

3.13.2 Types and minimum dimensions of access and inspection openings

Openings shall be elliptical or circular. See figures 11 and 13 a) to 13 i).

a) Handholes

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 shall not exceed 65 mm, or 100 mm if the neck or ring is conical.

b) Headholes

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 shall not exceed 100 mm, or 120 mm if the neck or ring is conical.

c) Manholes

In general, manholes should be not less than 320 mm × 420 mm or should have an inside diameter of 420 mm. The height of the neck or ring shall not exceed 300 mm. If in special cases manholes 300 mm × 400 mm are used, the requirements in the table of figure 13 h) shall be fulfilled.

3.13.3 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 gas-

ket shall have a minimum gasket bearing width of 15 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.

3.13.4 Access and inspection openings in flat plates

Where access and inspection openings are located in flat plates, the openings shall be suitably reinforced. Reinforcement shall be obtained by flanging the edge of the opening, or by the provision of a stiffening ring (see figure 11).

3.13.5 Inspection requirements

3.13.5.1 The efficiency of visual inspection depends in particular on the distance between eye and object and the angle under which the surface of the object is seen. Efficient visual inspection is best achieved by entering the boiler. The guidelines in this subclause are intended to ensure that a good visual examination of representative parts of the various welded seams is possible. It is recognized that it is not practicable to provide access for close visual inspection of every weld after the boiler has been constructed, particularly in the case of small boilers. However, it is also recognized that some parts of boilers are more prone than others to the occurrence of cracking or corrosion. The following inspection categories are arranged in order of relative importance and, for each category, appropriate facilities for the inspection of representative parts shall be provided. Means of achieving various degrees of visual inspection are illustrated in figure 13.

a) Inspection category 1

Corner welds (e.g. end plate to shell welds and furnace to end plate welds) except where hidden by tube nests. Attachment welds of stays and stiffeners.

NOTE 4 In the case of category 1 inspection, the representative parts of the welds are those where high bending moments are likely to occur, and would typically include half of the end plate to shell welds and half of the end plate to furnace welds.

b) Inspection category 2

All attachment welds not covered under a).

All large components subjected to high heat flux (e.g. furnaces).

Flanged corners where the boiler is not stayed end to end.

All parts where deposits could accumulate.

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Parts located in the vicinity of the water inlet or in the area where there are changes in the water level during operation and staybolts are used for anchoring.

c) Inspection category 3

All attachment welds not covered under a) and b) which are exposed to low heat flux (flue gas temperature less than or equal to 400 °C) or which are not exposed to flame.

The positions of inspection openings are based on two factors, the size of the opening and the length of the visual ray [see figure 13 g)] appropriate to the inspection category. These positions are shown in figures 13 c) to 13 f).

3.13.5.2 In the case of circumferential corner welds, not more than one single length equal to half the shell outside diameter or a number of lengths totalling one shell outside diameter shall be hidden by tube nests. Where necessary, the tube nest shall have suitable inspection lanes and the shell shall have headholes or handholes in sufficient number.

NOTE 5 In determining the hidden area between tubes and shell, it is assumed that the eye can be brought to within 80 mm of the internal surface.

3.13.5.3 In all cases it shall be possible to inspect the bottom of the shell and the longitudinal welds.

3.13.6 Requirements for entry to boilers with a shell outside diameter greater than 1 400 mm

3.13.6.1 The space available for entry along the length of the boiler shall include at least one cross-section which is comparable with one measuring 600 mm diameter. This requirement may be considered satisfied if the space includes an inscribed circle of at least 500 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 13 i), or a top manhole, as shown in figure 13 a), a clear height of 400 mm between the boiler shell (manhole surround) and the tube assembly is 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 need enter as shown in figure 13 c).

3.13.6.2 To pass from one inspection space into another, for instance a lateral space, it is sufficient to have a hole with a height of at least 300 mm at its narrowest point [see figure 13 i)]. Figure 13 i) merely explains the idea of such a "hole". The possible types need not all be available at the same time.

3.13.7 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., this shall be taken into account. In each case, the arrangement of the entry and inspection openings, along or at right angles to the boiler axis, shall be used to make the inspection conditions as favourable as possible.

3.14 Stays, stiffeners and supported surfaces

3.14.1 Breathing spaces

Stays shall give breathing spaces around the furnace connections and tube nests (see figure 14) and equally divide the unstayed areas. Breathing spaces between furnaces and tube nests shall be a minimum of 50 mm or 5 % of the shell outside diameter, whichever is the larger, but need not be more than 100 mm.

Breathing spaces between furnaces and shells shall be as given in table 2 but shall be not less than 50 mm or, for bowling hoop furnaces, not less than 75 mm.

Table 2 — Breathing spaces between furnaces and shells when the thickness of the end plate is 25 mm or less

Design	Length between boiler end plates L_b m	Breathing space	
		percentage of outside diameter	maximum ¹⁾ mm
In-serted flat ends	$L_b \leq 5,5$	5	100
	$5,5 < L_b \leq 6$	5,5	110
	$6 < L_b \leq 6,5$	6	120
Flanged ends	any length	5	100
1) But not less than 50 mm or, for bowling hoop furnaces, not less than 75 mm.			

Breathing spaces 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 greater than 1 800 mm or a furnace length greater than 6 000 mm, in

which case the breathing spaces shall be not less than 250 mm, and

- 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.

Breathing spaces between gusset or link stays and tube nests shall be not less than 100 mm.

All other breathing spaces shall be a minimum of 50 mm or 3 % of the shell outside diameter whichever is the larger but need not be more than 100 mm.

3.14.2 Stayed flat surfaces

3.14.2.1 Radius of flange

Where flat ends are flanged, the inside radius of flanging shall be at least 1,5 times the thickness of the plate, but not less than 35 mm.

3.14.2.2 Point of support

Where the flange curvature is a point of support, the point of support shall be taken at half the distance between the inside of the shell and the commencement of curvature, or at a line 3,5 times the thickness of the plate measured from the outside of the plate, whichever is nearer to the flange (see figure 15). Where a flat plate is welded directly to a shell or wrapper, the point of support shall be taken at the inside of the shell or wrapper plate.

3.14.2.3 Thickness

The thickness of those portions of flat plates supported by stays shall be determined from the following formulae:

$$e = e_{cp} + c \quad \dots (3.42)$$

$$e_{cp} = C_1 b y \sqrt{\frac{p}{f}} \quad \dots (3.43)$$

The corrosion allowance is

$$c = 0,75 \text{ mm for } e_{cp} \leq 30 \text{ mm}$$

$$c = 0 \text{ mm for } e_{cp} > 30 \text{ mm}$$

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 16 or 17 with a diameter equal to 0,75 times the diameter of the

main circle, lies outside the main circle), y , taken from figure 18, shall be determined using dimensions a and b as indicated in figure 16 or 17. 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 unstayed areas of rectangular shape, the dimensions a and b shall be as indicated in figure 14.

3.14.2.4 Values of constant C_1

Where various forms of support apply to the portion of flat plate under consideration, the constant C_1 shall be the mean of the values for the respective methods adopted.

The value of constant C_1 in formula (3.43) shall be as follows.

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 ratio $D_L/D_b = 1$	0,45
when ratio $D_L/D_b = 1,3$	0,6
when 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
Corner stays or bar stays	0,3
Gusset stays in which the angle θ is greater than 30° (see figure 19)	0,45
Unstayed tube nest with plain tubes welded at both ends	0,3
Plain furnace less than 6 m long	0,3
Corrugated furnace with corrugation depths ≤ 50 mm	0,32
Corrugated furnaces with corrugation depths > 50 mm:	
with a length ≤ 4 m	0,35
with a length > 4 m	0,37
Bowling hoop furnaces	0,35
Isolated plain bar stays (see figure 20) or isolated stay tubes (see figure 21)	0,45
Non-isolated plain bar stays (see figure 20) or non-isolated stay tubes (see figure 21)	0,39
Bar stays or stay tubes shall be considered isolated if there are less than three in a group outside the tube nest.	
Bar stays with washers [see figures 22 a) and 22 b)]	0,35

Bar stays with washers [see figures 22 c) and 22 d)]	0,33
Reversal chamber bar stays (see figure 23)	0,39
Reversal chamber access openings welded from both sides	0,3
Reversal chamber access opening (where not possible to effect back weld) (see figures 39 and B.20)	0,45
Flat unflanged end plates welded to the shell from both sides with the following end plate thickness to shell plate thickness ratios:	
$\leq 1,4$	0,33
$> 1,4 \leq 1,6$	0,36
$> 1,6 \leq 1,8$	0,39
$> 1,8 \leq 2$	0,42
Flat surface of reversal chamber reinforced by stiffeners continuously welded above or flush stiffeners equipped with waterways [see figures 24 a) to 24 e)]. For 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 11), when the distance from the edge of the manhole ring to the edge of the furnace, smoke tubes or shell is not more than four times the end plate thickness [see figures 25 a) and 25 b)]: the following single value shall be used	0,27

If the distance exceeds four times the end plate thickness, the manhole is ignored, and the constant C_1 shall be determined in the normal manner, from the mean of the values for the respective methods of attachment given above.

3.14.2.5 Stays for wet back reversal chambers

The permissible stress in the stays calculated on the net sectional area shall not exceed 70 N/mm². The diameter of any stay shall be not less than 20 mm.

The stays shall comply with the following rule (see figure 26):

$$\frac{d_s L_1}{L_2^2} \leq 2 \quad \dots (3.44)$$

3.14.2.6 Longitudinal bar stays

The diameter of each bar stay shall be such that the stress calculated on the least sectional area shall not exceed 70 N/mm². The diameter of any stay at any part shall not be less than 25 mm.

Supports shall be provided for longitudinal bar stays of 5 000 mm in length and longer.

3.14.2.7 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 follows.

- 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, in millimetres, 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.
- For a stay tube in the boundary row, or for a bar stay, the net area to be supported shall be the area, in millimetres squared, enclosed by lines 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 14.
- 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.

3.14.2.8 Gusset and link stays (corner stays)

3.14.2.8.1 Load on each stay

Each gusset or link stay supporting the flat end plate of a boiler shall be designed to carry the whole load due to 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 19).

3.14.2.8.2 Gusset stays

Gusset stays shall be so proportioned that the angle V (see figures 27 and 28) is not less than 60°. The minimum cross-section of the gusset shall be determined in accordance with the following equation:

$$e_g h = \frac{1,33W}{f \sin V} \quad \dots (3.45)$$

where

$$e_g \leq 1,7 \times \text{shell plate thickness}$$

and

$$e_g \geq 1 \times \text{shell plate thickness}$$

$$e_g \geq 0,7 \times \text{end plate thickness}$$

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.

Gusset stays shall be fitted radially and there shall be no sudden changes of contour in the gusset stay profiles.

3.14.2.8.3 Link stays

Link stays shall be so arranged that the angle V (see figure 29) is not less than 60° and the dimensions shall be such that the stress in the stay at its weakest part does not exceed $f/1,67$.

3.14.2.8.4 Anchor plates, angles and link pins, etc.

The strength of anchor plates, angles and link pins calculated at the weakest section shall be as follows.

- The shear stress in link pins shall not exceed 55 N/mm^2 .
- Anchor plates or angles shall be so designed that the calculated stress does not exceed $f/1,67$, but in no case shall the thickness be less than $0,875$ of the thickness of the shell plate, with a minimum of $12,5 \text{ mm}$.

The part of the anchor plate or angle attached to the end plate shall extend from the inner limit of the breathing space to the outer limit of the furnace or tube breathing space.
- Links, anchor plates and pins shall be constructed from material having a minimum specified tensile strength of 430 N/mm^2 and shall be so designed that the compressive stress on the projected area does not exceed 100 N/mm^2 .

3.14.2.8.5 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 27.

Where anchor plates or angles are welded to the shell and/or end plates (see figures 28 and 29) the attachment shall be by means of full penetration welds. The welds shall be of such dimensions that the stress calculated on an area equal to the effective length of the weld multiplied by the effective throat thickness shall not exceed that permitted for the parent metal multiplied by the appropriate weld factor given in table 3.

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

For the purposes of stress calculation, the effective throat thickness of a butt weld shall be taken as the thickness of the gusset or anchor plate. For compound welds, the effective throat thickness shall be the sum of the constituent parts. The effective throat thickness of the fillet weld shall be taken as $0,7$ of the fillet size L_o (see figure 12).

Table 3 — Weld attachments

Form of weld	Weld factor
Single-J or single-bevel butt welds (with or without superimposed fillets)	Without back weld 0,45
	With back weld 0,7
Double-J or double-bevel butt welds (with or without superimposed fillets)	0,8

3.14.2.9 Additional requirements for unflanged flat end plates

3.14.2.9.1 General

In addition to the applicable requirements, especially in respect of acceptable weld details (see section 5 and annex B), and to the general requirements for flat end plates given in 3.14.2.2 to 3.14.2.8, the requirements for welded-on or welded-in unflanged flat end plates given in 3.14.2.9.2 to 3.14.2.9.4 shall be taken into consideration.

3.14.2.9.2 Post-weld heat treatment of steel PH 290

Where steel PH 290 is used for shell or end plates in boilers incorporating flat unflanged end plates, the boiler shall be subjected to post-weld heat treatment in accordance with 5.4 irrespective of the plate thickness.

3.14.2.9.3 Shell plate thickness local to the corner joint

For the determination of the shell plate thickness local to the corner joint equations corresponding to formulae (3.6) and (3.7) shall be used:

$$e = e_{cs} + c$$

where

$$c = 0,75 \text{ mm (corrosion allowance);}$$

$$e_{cs} = \frac{pd_o}{2fx + p} \quad \dots (3.46)$$

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The stress reduction factor x in formula (3.46) depends on the ratio of the end plate to shell plate thickness as follows:

$$\begin{aligned} e_{cp}/e_{cs} &\geq 1,4 & x &= 0,8 \\ e_{cp}/e_{cs} &\leq 1 & x &= 1 \end{aligned}$$

If the shell thickness e_{cs} is calculated according to formula (3.7) with a weld factor $v = 0,8$ the stress reduction factor x need not be considered.

For values of e_{cp}/e_{cs} between 1 and 1,4 the values of x shall be determined by linear interpolation.

increase 100 mm to 110 mm

- g) When the actual thickness of the end plate exceeds 25 mm, the breathing spaces in accordance with table 2 shall be increased in accordance with table 5.

NOTE 6 In order to keep the thickness of the end plate as small as possible it is recommended that an appropriate number of stays be provided.

3.14.2.9.4 Design parameters

Unflanged flat end plates shall comply with the parameters given in table 4, and with the requirements given in a) to g) as follows.

- The wall thickness of the shell shall be calculated in accordance with formula (3.6), including the stress reduction factor x [see formula (3.46)].
- The actual wall thickness of the end plate shall not exceed 30 mm.
- When the wall thickness of the shell exceeds 30 mm, the through thickness properties of the material of the shell shall be proved by tests.³⁾
- 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 5.3.2.5.2.
- Both end plates shall be adequately stayed by using plain bar stays, stay tubes or gusset stays. (Stiffening ribs which are not connected to the shell are not permitted.)
- The breathing spaces between gussets or link stays and furnaces required in accordance with 3.14.1 shall be increased as follows:

increase 250 mm to 275 mm

increase 200 mm to 220 mm

increase 150 mm to 165 mm

Table 4 — Design parameters for unflanged flat end plates

Shell outside diameter d_{os} mm	Length between boiler end plates L_b m	Design pressure N/mm ²	Ratio of end plate and shell thickness e_{cp}/e_{cs}
$d_{os} \leq 1500$	$L_b \leq 5,5$	≤ 2	≤ 2
		> 2	$\leq 1,6$
	$5,5 < L_b \leq 6,5$	≤ 2	$\leq 1,8$
		> 2	$\leq 1,4$
$1500 < d_{os} \leq 1800$	$L_b \leq 5,5$	$\leq 1,6$	$\leq 1,8$
		$> 1,6$	$\leq 1,4$
	$5,5 < L_b \leq 6,5$	$\leq 1,6$	$\leq 1,6$
		$> 1,6$	$\leq 1,2$
$1800 < d_{os} \leq 2500$	$L_b \leq 5,5$	$\leq 1,6$	$\leq 1,7$
		$> 1,6$	$\leq 1,3$
	$5,5 < L_b \leq 6,5$	$\leq 1,6$	$\leq 1,5$
		$> 1,6$	$\leq 1,1$
$d_{os} > 2500$	$L_b \leq 5,5$	$\leq 1,6$	$\leq 1,6$
		$> 1,6$	$\leq 1,2$
	$5,5 < L_b \leq 6,5$	$\leq 1,6$	$\leq 1,4$
		$> 1,6$	≤ 1

3) Test requirements, e.g. minimum elongation 16 %, minimum strength and reduction of area values, will form the subject of a future addendum to this International Standard.

Table 5 — Breathing spaces between furnaces and shells when the thickness of the end plate exceeds 25 mm

Length between boiler end plates L_b m	Breathing space		
	percentage of outside diameter	maximum mm	minimum mm
$L_b \leq 5,5$	6,5	130	65
$5,5 < L_b \leq 6$	7	140	70
$6 < L_b \leq 6,5$	8	150	75

3.14.2.10 Prohibited stiffeners

Reinforcement of flat end plates by stiffeners (fillets, bars or angles) which are not connected to the opposite end plate or to the shell are not permitted.

3.14.2.11 Girder stays supporting the top end plates of reversal chambers

The thickness of welded-on girders in accordance with figures 24 a) to 24 e) shall be calculated in accordance with the following formula, but in no case shall the thickness exceed 35 mm:

$$e = \frac{pL_g^2 S}{1,33d_g^2 f} \quad \dots (3.47)$$

where e is the girder thickness.

3.15 Unpierced tubes and pipes, and tube plates

For the purposes of this International Standard, tubes are cylindrical components used for heat transfer duties.

3.15.1 Thickness of straight tubes subject to external pressure

The thickness of straight tubes up to and including 150 mm outside diameter subject to external pressure shall be not less than that given by the following formulae or 2,9 mm, whichever is the greater. Minus tolerances shall be taken into account.

$$e = e_{ct} + c \quad \dots (3.48)$$

where

$$c = 0,75 \text{ mm (corrosion allowance);}$$

$$e_{ct} = \frac{pd_o}{1,6f} \quad \dots (3.49)$$

3.15.2 Thickness of straight tubes subject to internal pressure

The thickness of straight tubes subject to internal pressure shall be not less than that given by the following formulae or 2,5 mm, whichever is the greater. Minus tolerances shall be taken into account.

$$e = e_{ct} + c$$

where

$$c = 0,75 \text{ mm (corrosion allowance);}$$

$$e_{ct} = \frac{pd_o}{2f + p} \quad \dots (3.50)$$

3.15.3 Thickness of straight pipes subject to internal pressure

The thickness of straight pipes subject to internal pressure shall be not less than that given by the formulae in 3.15.2 or 4 mm, whichever is the greater. Minus tolerances shall be taken into account.

3.15.4 Wall thickness and ovality of elbows, tube bends and pipe bends (see figure 30)

The wall thickness of elbows, tube bends and pipe bends up to and including 150 mm outside diameter shall be not less than that given by the following formulae:

wall thickness at the intrados

$$e_i = e_{ct} C_i \quad \dots (3.51)$$

wall thickness at the extrados

$$e_o = e_{ct} C_o \quad \dots (3.52)$$

where e_{ct} is the thickness calculated for a straight tube or pipe in accordance with 3.15.1, 3.15.2 or 3.15.3 as appropriate, and C_i and C_o are factors to be taken from figure 31.

The factors C_i and C_o are valid for elbows, tube bends and pipe 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 or pipes.

Minimum wall thicknesses, corrosion allowances and minus tolerances shall be taken into account in accordance with 3.15.1, 3.15.2 or 3.15.3 as appropriate, except that in no case shall the wall thickness be less than 2,9 mm.

The value of d_m/e shall not exceed 40.

Ovality measured at the end after bending shall not exceed 10 %.

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Ovality is defined as

$$u = \frac{d_{o \max} - d_{o \min}}{d_o} \times 100 \quad \dots (3.53)$$

where

$d_{o \max}$ is the maximum outside diameter of the tube or pipe measured at the bend apex;

$d_{o \min}$ is the minimum outside diameter of the tube or pipe measured at the same cross-section as $d_{o \max}$;

d_o is the outside diameter of the straight tube or pipe.

3.15.5 Stay tubes

Stay tubes are tubes welded in accordance with figure 21 having a weld depth equal to the tube thickness plus 3 mm. These stay tubes are not required within tube nests except when the tube nests comprise tubes which are expanded only [see figure 32 a)].

When the tube nests are comprised of plain tubes which are expanded and beaded, expanded and belled [see figure 32 b)], or expanded and welded in accordance with figures 32 c), 32 d) and 32 e), welded stay tubes in accordance with figure 21 are required in the boundary rows to carry the flat plate loadings.

Where tube nests comprise plain tubes welded in accordance with figure 32 f) or having a weld depth equal to the tube thickness plus 2 mm no stay tubes are required.

Each stay tube shall be designed to carry its due proportion of the load on the plates which it supports. The thickness of stay tubes welded into tube plates shall be such that the axial stress on the thinnest part of the tube does not exceed 70 N/mm².

3.15.6 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,

$$0,125d + 12,5 \text{ mm}$$

b) for welded tubes,

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

$$0,125d + 9 \text{ mm}$$

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

$$0,125d + 7 \text{ mm}$$

3.15.7 Thickness of the tube plates within tube nests

The thickness of tube plates shall be calculated from formulae (3.42) and (3.43), except when

- the tubes are expanded into the tube plate, in which case the minimum thickness of the tube plate shall be 12,5 mm when the diameter of the tube hole does not exceed 50 mm, or 14 mm when the diameter of the tube hole is greater than 50 mm, or
- the tubes are attached to the tube plates by welding only, in which case the tube plates shall be not less than 6 mm thick for boilers with design pressures less than 0,5 N/mm², and not less than 9 mm thick for boilers with design pressures greater than or equal to 0,5 N/mm².

3.16 Furnaces and wet back reversal chambers of cylindrical form subject to external pressure

3.16.1 Furnaces and wrapper plates

3.16.1.1 Plain furnaces and wrapper plates

The design pressure of plain furnaces and wrapper plates of wet back reversal chambers shall be the lower of the design pressures obtained using the following equations:

$$p = \frac{R_{p0,2}}{S_1} \times \frac{2e_{cf}}{d_m} \times \frac{1 + 0,1d_m/L}{1 + (0,03d_m/e_{cf}) [u/(1 + 5d_m/L)]} \quad \dots (3.54)$$

$$p = \frac{2,6E}{S_2L} \left(\frac{e_{cf}}{d_m} \right)^2 \sqrt{d_m e_{cf}} \quad \dots (3.55)$$

The preceding equations may be expressed in terms of thickness as shown in formulae (3.56) and (3.58). The greater of the thicknesses obtained shall be used, but the thickness 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 minimum wall thickness of not less than 10 mm. In no case shall the thickness exceed 22 mm. For wrapper plates the maximum thickness shall not exceed 35 mm.

$$e_{cf} = \frac{B}{2} \left[1 + \sqrt{1 + \frac{0,12d_m u}{(1 + 5d_m/L)B}} \right] \quad \dots (3.56)$$

where

$$B = \frac{pd_m S_1}{2R_{p0,2} (1 + 0,1d_m/L)} \quad \dots (3.57)$$

$$e_{cf} = d_m^{0,6} (LS_2 p / 2,6E)^{0,4} \quad \dots (3.58)$$

$$e = e_{cf} + c \quad \dots (3.59)$$

where $c = 0,75$ mm (corrosion allowance).

Formulae (3.54) to (3.59) apply only to furnaces having diameters less than or equal to 1 800 mm.

NOTE 7 Formulae (3.54) and (3.56) are based on considerations of plastic collapse. Formulae (3.55) and (3.58) are based on considerations of elastic instability.

3.16.1.2 Corrugated furnaces

The design pressure of corrugated furnaces shall be determined using the following equation, but the thickness shall be not less than 10 mm nor greater than 22 mm:

$$p = \frac{R_{p0,2}}{S_1} \times \frac{2X_2}{p_c d_m} \times \frac{1 + 0,1d_m/L}{1 + \left[\frac{X_2 w d_m}{800 I_1} \times \frac{u}{1 + 5d_m/L(e_{cf}/w)^3} \right]} \quad \dots (3.60)$$

where d_m is the mean diameter.

NOTES

8 For corrugated furnaces the mean diameter is equal to the inside diameter plus the full depth of one corrugation, i.e. inside diameter plus $e_{cf} + w$.

9 Values of X_2 and I_1 for Fox and Morrison corrugations are given in figures 33 a) to 33 g).

3.16.1.3 Safety factors

The value of the safety factor is

$S_1 = 2,5$	for horizontal furnaces exposed to flame
$S_1 = 2$	for furnaces and wrapper plates not exposed to flame
$S_2 = 3$	for all conditions

3.16.2 Tolerances and corrosion allowances on wall thickness

For corrugated furnaces, the calculated wall thickness shall be the minimum thickness of the finished furnace. For plain furnaces and reversal chambers, allowance shall be made to take account of any minus tolerances on the plate thickness.

3.16.3 Out-of-roundness

The out-of-roundness, in per cent, of furnaces and reversal chambers shall be calculated as follows:

$$u = \frac{2(d_{\max} - d_{\min})}{d_{\max} + d_{\min}} \times 100 \quad \dots (3.61)$$

where

$d_{\max}$ is the maximum mean diameter of the furnace, in millimetres;

$d_{\min}$ is the minimum mean diameter of the furnace, in millimetres.

The maximum allowable out-of-roundness is given in 4.9.2.

3.16.4 Stiffeners

3.16.4.1 General

Stiffeners welded to furnaces with the maximum dimensions in accordance with figures 34 and 35 shall be regarded as fulfilling the requirements of this section and need not be calculated.

Stiffeners not conforming with figures 34 and 35 shall have a second moment of area not less than that given by the following equation:

$$I_2 = \frac{p d_m^3 L}{1,33 \times 10^6} \quad \dots (3.62)$$

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.

3.16.4.2 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 3.16.4.1. If it exceeds 22 mm or twice the furnace thickness it shall be tapered as shown in figure 35.

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

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3.16.4.3 Stiffeners located within the zone of peak heat flux

When stiffeners are welded on to furnaces which are more than 11 mm thick they shall not be located in the zone of peak heat flux, unless the net heat input to the furnace is restricted to not more than H_r in accordance with the following formula:

$$H_r = 130 - 2,7e_{rf} \quad \dots (3.63)$$

where H_r is the percentage of the maximum normally permitted net heat input, in watts.

The zone of peak heat flux shall be considered to extend for a length equal to two furnace diameters from the tip of the burner, or to the end of the grate, whichever is applicable.

NOTE 10 The requirements of 3.16.4.3 need not apply to boilers with a net heat input of less than 2 MW.

3.16.4.4 Bowling hoops

Bowling hoops shall be considered effective points of support. The minimum pitch of bowling hoop centres shall be not less than 600 mm. When bowling hoops are used, the furnace thickness shall be calculated in accordance with 3.16.1.1.

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

The second moment of area of the bowling hoop shall be not less than that required by 3.16.4.1. The length of plain furnace which may be included in the determination of I_2 shall be measured from the outside tangent line and shall not be greater than $0,55\sqrt{d_m e_{cf}}$. The dimensions of bowling hoops shall be in accordance with figures 36 a) to 36 c).

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

The second moment of area of bowling hoops between the outer tangent lines are as given in the tables to figures 36 a) to 36 c).

3.16.4.5 Stiffeners on corrugated furnaces

When corrugated furnaces are equipped with several stiffeners, e.g. one on each corrugation or on each second corrugation, the cross-sectional area and the second moment of area of the stiffeners shall be included when using formula (3.60). A height of not more than six times the furnace thickness shall be used for the calculation.

3.16.5 Calculation length of composite furnaces

When the length of the plain portion of a corrugated furnace 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.

3.17 Boiler supports**3.17.1 Leg supports**

For shell diameters of less than 1500 mm, leg supports or saddle supports with a subtended angle of not less than 60° may be used, provided that the shell thickness has been calculated using a stress reduction factor of $x = 0,8$.

3.17.2 Saddle supports

For shell diameters d_o equal to or greater than 1500 mm, leg supports are not permitted; only saddle supports may be used with a minimum subtended angle of not less than 90° . The shell thickness shall be such that the combined stress at the inner surface of the shell, obtained from formula (3.64) or (3.65), does not exceed $1,5f$.

If $L_s/r_{ms} > 8$, then

$$f_c = \frac{pr_{ms}}{e_{rs}} - \frac{Q}{4e_{rs}(B_2 + 10e_{rs})} + \frac{1,5C_3Q}{e_{rs}^2} \quad \dots (3.64)$$

If $L_s/r_{ms} \leq 8$, then

$$f_c = \frac{pr_{ms}}{e_{rs}} - \frac{Q}{4e_{rs}(B_2 + 10e_{rs})} + \frac{12C_3Qr_{ms}}{L_s e_{rs}^2} \quad \dots (3.65)$$

The width of the saddle top plate B_2 shall be not less than $10e_{rs}$.

The coefficient C_3 is obtained from figure 37.

Section 4: Workmanship and construction in fabrication other than welding

4.1 Plate Identification

In laying out and cutting the plates, the plate identification mark shall be so located as to be clearly visible when the pressure part is completed. Where the plate's identification mark is unavoidably cut out, it shall be transferred by the pressure part manufacturer to another part of this component to the satisfaction of the inspecting authority.

4.2 Cutting of forgings

Forgings should normally be cut to size and shape by machining and/or thermal cutting.

4.3 Cylindrical shells

4.3.1 Each ring shall be formed from not more than two plates, bent to cylindrical form to the extreme ends of the plate. The bending shall be done entirely by machine, and local heating or hammering shall not be used.

The longitudinal seam or seams may be placed in any suitable position(s), but the seams in successive rings should preferably not fall in line. In special cases they may be in line provided that the requirements of 5.3.2.2 are fulfilled.

4.3.2 The shell of completed boilers shall be in accordance with the following requirements.

a) Straightness

Unless otherwise shown on the drawing, the maximum deviation of the shell from a straight line shall not exceed 0,3 % both of the total cylindrical length and of any 5 m length. Measurements shall be made to the surface of the parent plate and not to a weld, fitting or other raised part.

b) Irregularities in profile

Irregularities in profile (checked by a 20° gauge) shall not exceed 5 % of the minimum plate thickness plus 3 mm. This maximum value may be increased by 25 % if the length of the irregularities does not exceed one-quarter of the length of the shell part between two circumferential seams, with a maximum of 1 m.

c) Out-of-roundness

The difference between the maximum and minimum diameter of any section of a shell welded longitudinally shall have a maximum of

$(D + 1\,250)/200$, where D is the nominal internal diameter expressed in millimetres.

Measurements shall be made to the surface of the parent plate and not to a weld, fitting or other raised part.

Shell sections may be measured for out-of-roundness either when laid flat on their sides or when set up on end. When the shell sections are checked when laid flat on either side, each measurement for diameter shall be repeated after turning the shell through 90° about its longitudinal axis. The two measurements for each diameter shall be averaged, and the amount of out-of-roundness calculated from the average values so determined.

Any local departure from circularity shall be gradual.

There shall be no flats or peaking at the longitudinal welded seam.

d) Cold rolling

Cold rolling of a welded shell to rectify a small departure from circularity is permitted, provided that non-destructive testing conforming to 5.5 and 5.9.4 is carried out after the departure from circularity has been remedied.

4.4 Tell-tale holes

Reinforcing plates and saddles of nozzles attached to the outside of a boiler shall be provided with at least one tell-tale hole (maximum size G 1/4) that may be tapped for a preliminary leakage test for tightness of welds that seal off the inside of the boiler. These tell-tale holes may be left open or may be plugged when the boiler is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the boiler wall.

4.5 End plates and tube plates

4.5.1 Where practicable, flat or dished ends shall be made in one piece except that, where the diameter is so large as to make this impracticable, flat ends may be made from two plates butt welded together (see figure B.19). The weld shall be located preferably between two rows of bar stays or, if there is only one row of bar stays, between this row and the top row of stay tubes. Dishing and peripheral flanging of end plates shall be done by machine. Such flanging should preferably be done in one operation, but where this is impracticable, creep ma-

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chine flanging may be permitted provided that the plate is worked at a suitable temperature and heated to an adequate distance beyond the portion under immediate treatment. Care shall be taken to see that the flanges are cylindrical, have a good surface condition, and are free from local irregularities.

End plates and tube plates shall not be flanged cold. The cold dishing of end plates is permitted subject to agreement between the parties concerned and in accordance with an agreed qualified procedure, including normalizing.

Plates which have been dished or flanged at non-uniform temperatures, or which have been locally heated, shall be normalized after forming unless otherwise agreed by the manufacturer and the inspecting authority.

Where flats are pressed (for example, in dished end plates for the attachment of mountings), they shall be formed with an ample radius at the junction of the flat and curved surfaces and be free from sharp corners or tool marks, and the plate shall not be unduly thinned.

On completion of all flanging and machining operations, flat portions of flat end plates shall be flat and free from set or distortion.

4.5.2 Where hemispherical shell end plates are pressed from one plate they shall be pressed to form by machine in progressive stages, without thinning, and shall be normalized on completion except that, when agreed between the parties concerned, normalizing may be omitted in the case of hot-formed ends, when the forming process is completed at temperatures exceeding approximately 850 °C.

4.5.3 Where dished ends are used they shall be flanged for connection to the shell.

4.6 Plain tubes and stay tubes

4.6.1 Tubes may be expanded or welded into the tube plate or secured by a combination of both methods.

4.6.2 Where the tubes are expanded only, the process shall be carried out with roller expanders, and the expanded portion of the tube shall be parallel through the full thickness of the tube plate. In addition to expanding, tubes may be flared, bell-mouthed or beaded.

4.6.3 Where tubes are welded to the tube plate by welds which are not full penetration welds, the unwelded portion of the tube within the tube hole shall be in full contact with the tube plate, except as permitted by 3.4 d).

4.6.4 Stay tubes shall be provided in all cases where the total number of tubes is arranged in more than one nest. Where stay tubes are not provided, the ends of all tubes shall be welded or expanded and beaded at the inlet end, and welded or expanded only at the outlet end.

4.6.5 Examples of stay tube welding attachments are shown in figures 21 a) to 21 e).

4.6.6 Plain tubes may be welded [see figures 32 c) to 32 f)] after stress relief of the boiler.

4.7 Manhole frames and openings

4.7.1 Material

Manhole frames, openings, doors and cover plates shall be of steel complying with the requirements specified in section 2.

4.7.2 Location

Manholes and other openings in shells shall be placed as far as practicable from any seam. Oval openings should preferably be arranged with the minor axis parallel with the longitudinal centre-line of the boilers. In no case shall the major axis of any opening exceed twice the minor axis of the opening.

Where a manhole is located in or in-between tube nests in multitubular boilers, or below the furnaces of twin-furnace boilers, the stay tubes in the boundary rows, or gusset stays, as applicable, shall be arranged as close as practicable to the manhole.

4.7.3 Frames

If the design pressure exceeds 1,8 N/mm², raised circular manhole mouthpieces shall not be fitted. In all other cases, where the shell thickness exceeds 14 mm, oval frames or circular mouthpieces may be fitted. Oval frames of the flanged type shall be formed to fit closely to the shell and to provide a flat jointing surface for the door. Where practicable, such frames shall be attached to the inside of the shell, with the minor axis parallel to the longitudinal centre-line of the boiler.

Oval frames and external raised circular openings shall be either formed in one piece without welding, or formed from a suitable rolled section fabricated by fusion welding. Welds in fabricated manhole frames and openings shall be positioned so that they are in a plane at right angles to the longitudinal axis of the boiler.

The joint face of manhole frames shall be not less than 15 mm wide.

Typical forms of manhole frames are shown in figures 11 and 12.

4.7.4 Jointing flanges

The jointing flanges of openings and covers shall be machined on the face and edges and on the bearing surface of the bolt heads and nuts. Bolts and nuts shall be machined where they are in contact with the flanges, and the joints should be formed inside and outside the pitch circle or pitch line of the bolts to preclude the possibility of flange distortion.

4.7.5 Doors

Doors shall be constructed in accordance with the following requirements.

- a) Doors shall be formed to fit closely to the internal joint surface and shall be fitted with studs, nuts and cross bars.
- b) Doors for openings larger than 250 mm by 175 mm shall have two studs, but for openings of 250 mm by 175 mm or less, only one stud need be fitted. Doors for openings not larger than 125 mm by 90 mm may have the stud forged integrally with the door.
- c) Door studs shall be of welding quality steel having a minimum specified tensile strength of 360 N/mm², and those for manholes shall be not less than 30 mm diameter. They shall be
 - 1) screwed through the plate and fillet welded on the inside, or
 - 2) fillet welded each side of the plate with a leg length of not less than 9,5 mm.
- d) The spigot part, or recess, of manhole and sight-hole doors shall be as neat a fit as practicable. In no case, however, shall the clearance all round exceed 1,5 mm.
- e) Nuts shall comply with appropriate national standards and shall be faced on the seating surface.
- f) Cross bars shall be of steel, forged or cut from plate having a minimum specified tensile strength of 360 N/mm². The seating surface shall be faced.

4.8 Seating for mountings

4.8.1 Seatings

Mountings over 25 mm internal diameter, except flanged mountings up to and including 75 mm bore, shall not be attached directly to any boiler plate, but

shall be carried on suitable forged, cast or fabricated steel seatings. These seatings shall take the form of short nozzles, forged pads or pads cut from plate or round bar as may be convenient. Where seatings are fabricated by fusion welding, they shall be stress relieved by heat treatment before attachment unless the whole boiler is to be subjected to heat treatment on completion.

4.8.2 Water gauges

Water gauges and pressure gauge siphons may be attached directly to the plate without the intervention of a pad or standpipe, provided that they are flanged and secured by studs. If the studs are screwed through the plate, nuts of full thickness shall be fitted on the inside of the boiler.

4.8.3 Flanges and pads

Flanges and pads in contact with the boiler shall be formed to fit closely to the plate to which they are to be attached.

4.8.4 Nozzles

Where nozzles are used, the flanges shall be machined or thermal-cut by machine on the edges. The bolting flanges shall be machined on the jointing and bolting surfaces.

4.8.5 Pads

Where pads are used, the jointing surfaces shall be machined. The pads shall have sufficient thickness to allow the drilling of the stud holes for mountings without the inner surface being pierced, and the length of the screwed portion of the stud in the pad shall be not less than the diameter of the stud.

4.8.6 Methods of attachment

The seatings shall be attached to the shell or end plates by one of the following methods.

- a) Where the internal diameter of the nozzle does not exceed 25 mm, the nozzle may be screwed through the plate, and either fitted with a nut, or seal welded on the water side. The screwed thread of the nozzle shall have a run-out of thread of not less than three times the pitch of the thread, produced by suitably grinding the cutting die. The threads in the tapped hole in the shell shall be chamfered to produce a corresponding angle of run-out.
- b) Where the design pressure does not exceed 1,2 N/mm², mountings with screwed ends not exceeding 25 mm diameter may be used. The screwed portion of any such mounting shall be an integral part thereof.

Such mountings may be screwed directly into the plates, nuts being fitted on the water side, or may be screwed into steel distance pieces (see figure 38), the length of the thread engaged being, in no case, less than the bore of the mountings plus 6,5 mm.

The distance pieces shall be made from forged steel or bar complying with the requirements specified in section 2. They shall be screwed into the plate and fitted with nuts on the water side. The walls of the distance pieces shall not be less than 6,5 mm thick at the bottom of the thread.

- c) Notwithstanding the requirements in 5.4, in special circumstances, and if approved by the inspecting authority, the seating may be welded to the plate without subsequent heat treatment, where the seating does not exceed 125 mm bore, or where, in the case of a pad, the diameter of the opening in the shell does not exceed 125 mm plus twice the thickness of the plate to which it is to be attached. If these limits are exceeded the method of stress relieving shall be agreed between the manufacturer and the inspecting authority.

Typical methods of attachment are shown in annex B, but other methods of equivalent efficiency may be used subject to agreement between the inspecting authority and the manufacturer.

4.8.7 Bolts and nuts

All bolt and stud holes shall be drilled, and bolts and nuts shall be machined where they are in contact with flanges.

4.9 Cylindrical furnaces

4.9.1 Sections of cylindrical furnaces shall each be made from one plate. Conical furnace sections may be made from not more than two plates. The longitudinal welds shall be at least 120° apart and shall be fusion butt welded in accordance with section 5. Alternatively, furnaces may be made from hot-finished seamless carbon steel tubes to ISO 2604-2, TS 9H, the tensile strength and minus tolerances on thickness being taken into account.

4.9.2 Out-of-roundness, as defined in 3.16.3, shall not exceed 1 % for corrugated furnaces or 1,5 % for plain furnaces with a maximum variation in diameter of any cross-section of 6,5 mm or half the thickness, whichever is the greater. There shall be no flats or peaks, and any departure from circularity shall be gradual.

4.9.3 The longitudinal welds of furnaces shall be placed in such a position that they can be examined from the water side in accordance with 3.13.5.1, category 2. Longitudinal welds in successive sections shall break joint by at least 150 mm.

4.9.4 Where the furnace sections are flanged for circumferential joints, the flanging shall be carried out at one heat by using suitable machinery. When furnace sections are flanged, they shall be normalized unless flanging is carried out above normalizing temperature.

4.9.5 Edges of all furnace flanges shall be machined or thermal-cut by machine.

4.9.6 Flanged circumferential seams shall be arranged so that they do not fall in line with those of the adjacent furnace.

4.9.7 Where stiffeners are required, they shall be attached externally by means of continuous full penetration welding in accordance with figure 34 or 35.

4.9.8 The dimensions of bowling hoops shall be as shown in figure 36 a), 36 b) or 36 c).

4.9.9 Forms of furnace connections to end plates are shown in figures B.17 a) to B.17 c). Where the furnace is inserted into a hole in the end plate, it shall be a good fit around the whole periphery.

4.10 Water-cooled reversal chambers

The attachment of the reversal chamber tube plates and end plates to the wrapper plate shall be in accordance with figures B.16 a) to B.16 e), and where the tube plate or end plate is flanged for connection to the wrapper plate, the weld shall be located between the commencement of curvature of the flange and the first row of stays.

Typical methods of attachment of access opening frames are shown in figure 39.

4.11 Stays

4.11.1 Bar stays

4.11.1.1 All bar stays shall be made from a solid rolled bar without weld in its length, except those attaching them to the plates they support. Bar stays which have been hot worked shall subsequently be normalized where justified by the hot-working procedure or material requirements, and with the agreement of the inspecting authority. It is recommended that when a stay is in position in the boiler, its axis shall be normal to the plate it supports.

It is recommended that a tell-tale hole be drilled along the axis of all bar stays. The diameter of the hole should not exceed 5 mm and the drilling should extend 15 mm min. beyond the water surface of the plate (see figure 20).

4.11.1.2 Bar stays shall be secured to the plates they support by one of the following methods:

- a) plain bars passing through clearing holes in the plates and welded thereto (see figure 20);
- b) plain bars passing through clearing holes in the plates and fitted with washers on the outside, the stay and washers being welded to the plates in accordance with any one of the methods shown in figures 22 a) to 22 d).

4.11.2 Gusset stays

Gusset stays shall be flat and perpendicular to the end plates.

4.11.3 Girder stays

The attachment of girder stays welded directly to the crown plates shall be by means of full penetration welds, and shall comply with the details shown in figures 24 a) to 24 e). Each girder shall be of sufficient strength to support its due proportion of the load on the top end plate independently of the crown plate, and the attachment welds shall have sufficient cross-sectional area to carry the applied load (see 3.14.2.11).

Section 5: Workmanship and construction in welding

5.1 General

5.1.1 The rules in this section are applicable to boilers and boiler parts that are fabricated by welding and shall be used in conjunction with the specific requirements that pertain to the class of materials used.

The welding and fabrication procedure to be agreed upon when steel containing more than 0,23 % carbon is used shall be appropriate to the grade of steel and shall be based on established International Standards or national standards with a record of reliability. It shall take into account all aspects of fabrication as covered by sections 4 and 5 of this International Standard.

5.1.2 The welding shall be executed in conformity with the qualified welding procedure which is in accordance with the welding procedure specification (see 5.8.3).

5.1.3 The welder shall be qualified in conformity with the welder's competence tests specified (see 5.8.4).

5.1.4 The manufacturer of a boiler or boiler part built in accordance with the requirements of this International Standard is responsible for the welding done for this purpose by his workmen. He shall designate a competent welding supervisor and conduct the tests required to qualify the welding procedure he uses and the competence of the welders who apply this procedure. No production work shall be undertaken until both the welding procedure and the welders or welding operators have been qualified.

5.1.5 The manufacturer shall maintain a record of the results obtained in welding procedure qualifications and competence tests. These records shall be certified by him and give an accurate description of all the particulars of the materials and procedure concerned and shall be accessible to the inspecting authority who shall witness and certify the tests (see the model forms in annex F).

5.1.6 A record shall be kept to show that the welder has been employed on works of the kind covered by his competence tests during the previous 6 months. The records shall contain the results of the welder's competence tests and the identification mark assigned to each welder (see the model forms in annex F) and shall be certified by the

manufacturer and be accessible to the inspecting authority.

5.1.7 The welds made by each welder shall be marked with a stamp showing the welder's identity or else some other appropriate record shall be made.

If hard stamping is employed, only low-stress stamps shall be used. (Low-stress stamps are those with radiused edges or those made of a series of dots.)

5.1.8 If, during the construction of a boiler or pressure part, the inspecting authority finds that the work is not satisfactory or is not in accordance with the requirements of this International Standard, the causes should be investigated by the manufacturer and rectified.

5.1.9 If it is proved that the welder is responsible for bad work, a decision should be taken, after consulting the welder's record, as to whether he should be requalified.

5.1.10 This decision should be recorded in the register.

5.2 Materials

5.2.1 The materials shall meet the provisions of section 2.

5.2.2 The welding consumables and flux [see 5.8.3.3 b) and 5.8.4.5.4] shall satisfy the requirements specified herein.

5.3 Design

5.3.1 Introduction

These rules apply to the design of boilers and boiler parts that are manufactured by welding and shall be used in conjunction with section 3 of this International Standard.

5.3.2 Design of welded joints

5.3.2.1 Weld deposition

The design of the welded joints shall be such as to provide adequate access for the deposition of weld metal to meet the requirements laid down in this International Standard.

5.3.2.2 Weld crosses

Joints where more than two welded seams meet shall be avoided. If the design cannot permit this, the appropriate precautions shall be taken into consideration and shall be agreed between manufacturer, purchaser and inspecting authority.

5.3.2.3 Non-pressure parts

Attachment of non-pressure parts by welds which cross or for which the minimum nominal distance between the edge of the attachment weld and the edge of existing main welds or nozzle welds is less than the smaller of twice the thickness of the pressure part or 40 mm shall be avoided.

If such welds cannot be avoided, they shall cross the main weld completely rather than stopping abruptly near the main or nozzle weld, in order to avoid stress concentrations in these areas.

If the design cannot permit this, the appropriate precautions shall be taken into consideration. These precautions shall be agreed between manufacturer, purchaser and inspecting and/or regulating authority.

5.3.2.4 Properties

Connections of nozzles, pads, branches, pipes and tubes, and non-pressure parts, may be welded to pressure parts provided that the properties of the material of all the pressure parts are not influenced adversely.

5.3.2.5 Permissible weld types

Typical examples of acceptable weld details of welded connections are indicated in annex B.

5.3.2.5.1 Full penetration welds

A full penetration weld is one in which the components of the joint are completely fused together through the full depth of the joint and there are no unwelded lands. In some cases the full penetration welds are reinforced by fillet welds.

The following welds shall be of the fully penetrated type:

- a) longitudinal and circumferential main seams in cylindrical shells, furnaces and reversal chamber wrapper plates as shown in figures B.18 a) to B.18 d);
- b) seams in flat end plates as shown in figures B.19 a) and B.19 b);
- c) unflanged flat end plates or tube plates where they are welded

- 1) to shells as shown in figures B.15 a) to B.15 d),
- 2) to furnaces as shown in figures B.17 a) and B.17 b),
- 3) to reversal chamber wrapper plates as shown in figures B.16 b) to B.16 e), and
- 4) to access tubes as shown in figure B.20;
- d) attachment of flanged end plates
 - 1) to reversal chamber wrapper plates as shown in figure B.16 a), and
 - 2) to furnaces as shown in figure B.17 c);
- e) compensating plates in accordance with figure 12 b);
- f) manhole frames in accordance with figure 11 a);
- g) gusset stay attachment welds as shown in figures 27 and 28;
- h) stiffener to furnace welds as shown in figures 34 and 35;
- i) reversal chamber girders as shown in figures 24 a) to 24 e);
- j) reversal chamber stays as shown in figure 23 b);
- k) welds of reinforcing branches, nozzles and pads as shown in figures B.3 to B.12.

5.3.2.5.2 Fillet welds (back welding)

When unflanged flat end plates or tube plates are welded to shells, furnaces and reversal chamber wrapper plates, the fillet welds shall be inserted for the full circumference of the seam, except as permitted for small boilers in accordance with table 6.

The above requirements for fillet welds are dictated by consideration of accessibility for welding. Notwithstanding these requirements, the fillet welds shall be inserted for the full circumference of the seam whenever it is possible to provide the requisite quality of finished weld.

The profile of the fillet welds shall be such as to minimize harmful notch effects.

When sections of the fillet welds are omitted in accordance with table 6, special consideration shall be given to the welding technique to ensure sound root conditions, which shall be proved by procedure tests.

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

Unwelded length	Boiler length between end plates	Outside diameter of shell	Minimum breathing space between furnace and shell	End plate thickness	Test pressure	Ratio of end plate to furnace wall thickness	General requirements for welded sections
	L_b	d_o		e_{rep}	p_t	e_{rep}/e_{rf}	
mm	mm	mm		mm			
≤ 250	$\leq 3\,000$	$\leq 1\,400$	6,5 % of d_o or 65 mm whichever is the greater	≤ 20	according to 6.3.1.1	$\leq 1,4$	The weld shows proper penetration ¹⁾ . Thorough inspection of the weld is possible. The weld is not heated directly.
> 250	$\leq 2\,500$	$\leq 1\,000$	$\geq 65\text{ mm}$	≤ 15	$\geq 2,55p$		
2)	$\leq 2\,000$	$\leq 1\,200$	$\geq 80\text{ mm}$	≤ 20	$\geq 2,1p$		

1) 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.

2) 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.

5.3.2.5.3 Welds other than full penetration welds

The following are examples of welds which are not full penetration welds:

- stay tube to tube plate welds as shown in figures 21 a) to 21 e);
- plain tube to tube plate welds as shown in figures 32 c) to 32 f);
- bar stay welds as shown in figures 20, 22 a) to 22 d) and 23 a);
- fillet welds attaching compensating plates as shown in figures 12 a) and 12 b).

5.3.2.6 Welding grooves

The dimensions and shape of the edges to be joined shall be such as to permit sound welds. [See 5.3.2.1 and 5.8.3.3 c).]

5.3.2.7 Tapered plate edges

If plate edges of unequal thickness are abutted, and if the difference between the surfaces on either side exceeds that specified in 5.8.11, the thicker plate shall be trimmed to a smooth taper for a distance not less than four times the offset including, if so desired, the width of the weld.

5.3.2.8 Welded joints subjected to bending stresses

5.3.2.8.1 Where it is known that local stresses due to geometrical discontinuities are unacceptably high, the weld contours shall be smooth. Where necessary, this may be accomplished by grinding and/or the addition of weld metal.

5.3.2.8.2 Corner joints with fillet welds shall not be used.

5.4 Heat treatment and post-weld heat treatment

5.4.1 Post-weld heat treatment in accordance with 5.8.16.1 shall be carried out after completion of all welding, and prior to the pressure test in the case of boilers where the wall thickness at any welded connection exceeds 30 mm, except as required by 3.14.2.9.2.

When welded repairs have been made to a vessel which has been heat treated, the vessel may again be heat treated. The decision as to whether heat treatment is necessary is left to an agreement between the manufacturer and inspecting and/or regulating authority.

5.4.2 When the welded joint connects parts that are of different thickness, the thicknesses to be considered in applying the limits mentioned in the requirements for post-weld heat treatment shall be the following nominal thicknesses, including corrosion allowance:

- a) the thickness of the shell or head plate in nozzle attachment welds;
- b) the thickness of the nozzle neck at the joint in nozzle neck to flange connections;
- c) the thickness of the pressure part, at the point of attachment, where a non-pressure part is welded to a pressure part;
- d) the thinner of two adjacent butt-welded plates including dished end to shell connections;
- e) the thickness of the shell in connections to flat plates which are butt welded to the shell;
- f) the thickness of flat plates where these are inset into the shell.

5.5 Non-destructive testing

5.5.1 General

For the purposes of this International Standard the term "non-destructive testing" covers the conventional techniques of radiographic, ultrasonic, magnetic particle and/or liquid penetrant testing as specified in 5.5.5, 5.9, annexes G and H, ISO 3452, ISO 3453 and ISO 3059. Percentages given in table 7 relate to each seam.

5.5.2 Procedure and interpretation

Except where otherwise stated in this International Standard, the procedure and interpretation of results shall be agreed upon between manufacturer and inspecting and/or regulating authority.

5.5.3 Non-destructive testing of repairs

On completion of repairs, the re-welded portions shall be examined by all techniques specified for the original weld.

5.5.4 Manufacturing in series

Until the results of future work are available, the amount of non-destructive testing in the case of manufacturing in series shall be subject to agreement between manufacturer and inspecting and/or regulating authority.

5.5.5 Extent of non-destructive testing

5.5.5.1 Shell seams

When the weld factor $v = 0,8$ is employed, 10 % of the length of the longitudinal and circumferential

butt-welded seams and all butt-welded intersections shall be non-destructively tested.

When the weld factor $v = 1$ is employed, 100 % of the length of the longitudinal and 25 % of the circumferential butt-welded seams shall be non-destructively tested. When the end plates are fully stayed to each other by bar stays, stay tubes or a combination of bar stays and reversal chamber stays, 10 % of the length of the circumferential seams shall be non-destructively tested. All seam intersections shall be non-destructively tested.

The non-destructive testing techniques employed shall be radiographic and/or ultrasonic.

5.5.5.2 End plate to shell seams and end plate to furnace seams

When the end plates are fully stayed to each other as described in 5.5.5.1, end plate to shell seams of the type shown in figures B.15 a) and B.15 b) shall be non-destructively tested for 10 % of their length, and the end plate to furnace seams of the type shown in figures B.17 a) and B.17 b) shall be non-destructively tested for 25 % of their length.

When the end plates are not fully stayed to each other, 100 % of the end plate to shell and end plate to furnace seams shall be non-destructively tested.

100 % of the length of end plate to shell seams of the type shown in figures B.15 c) and B.15 d) shall be non-destructively tested.

The non-destructive testing technique employed shall be ultrasonic, where practicable, or otherwise the following procedure shall be adopted:

- a) visual examination of weld preparation,
- b) visual examination after tack welding, and
- c) visual examination after initial root run,

unless alternative techniques are acceptable to the inspecting authority.

5.5.5.3 Internal fillet welds

The full length of internal fillet welds (back welds) shall be visually examined to ensure that they are of the correct shape without significant under-cutting (see 5.8.13).

5.5.5.4 Butt-welded seams in end plates

100 % of the length of butt-welded seams in end plates shall be non-destructively tested by radiographic and/or ultrasonic techniques.

Table 7 — Extent of radiographic or ultrasonic testing for butt welds

Com- ponent	Type of weld	Weld location	Figure No.	Testing technique	Notes	Percentage of total length of weld to be tested
Shell	Longitudinal	In shell sections	B.18	Radiographic or ultrasonic	1, 2 and 4	100
	Circumferential	Between shell sections	B.18	Radiographic or ultrasonic	1, 2 and 4	25
	Circumferential	Between shell sections and flanged end plates	B.18	Radiographic or ultrasonic	1, 2, 4 and 5	25
	Circumferential	Between shell sections and set-on end plates	B.15 c) and B.15 d)	Radiographic or ultrasonic	—	100
	T-butt	At junction of shell with set-in end plates	B.15 a) and B.15 b)	Ultrasonic	2 and 3	10
Flat end plates	Butt	Between the two sections in large diameter end plates	B.19	Radiographic or ultrasonic	2	100
Furnaces	Longitudinal	In furnace sections	B.18	Radiographic or ultrasonic	1 and 2	10
	Circumferential	Between furnace sections	B.18	Radiographic or ultrasonic	1 and 2	10
	Circumferential	Between furnace sections and bowling hoops	B.18	Radiographic or ultrasonic	1 and 2	10
	Circumferential	Between furnace sections and flanged end plates	B.17 c)	Radiographic or ultrasonic	1 and 2	10
	T-butt	Between furnace sections and set-in end plates	B.17 a) and B.17 b)	Ultrasonic	2 and 3	25
	T-butt	Furnace to reversal chamber end plate	B.17 a) and B.17 b)	Ultrasonic	2 and 3	25
	T-butt	Between furnace sections and cyl- indrical components	B.4, B.5, B.6 and B.7	Ultrasonic	2	25
Reversal cham- bers	Longitudinal	In wrapper plate	B.18	Radiographic or ultrasonic	2	10
	Circumferential	Between wrapper plate and flanged end plate	B.16 a)	Radiographic or ultrasonic	1 and 2	10
	T-butt	Between wrapper plate and set-in end plate	B.16 b) to B.16 e)	Ultrasonic	2 and 3	10

Com- ponent	Type of weld	Weld location	Figure No.	Testing technique	Notes	Percentage of total length of weld to be tested
Reversal chamber access tube	Longitudinal	In access tube	B.18	Radiographic or ultrasonic	2	10
	T-butt	Access tube to boiler and reversal chamber end plates	39 and B.20	Ultrasonic	2 and 3	10

NOTES

- 1 The tests shall include each intersection of longitudinal and circumferential seams. For each longitudinal and circumferential seam there shall be at least one radiograph, or where ultrasonic testing is specified, at least a 200 mm length shall be examined.
- 2 In each case the section of weld to be tested shall be selected at random.
- 3 The position of the tested section of weld shall be marked on the boiler and recorded.
- 4 See 5.5.5.1.
- 5 When the flange is thicker than the end plate, the flange shall be machined to a taper and welded in a manner similar to that shown in figure B.19 a).

5.5.5.5 Furnace and reversal chamber seams

10 % of the total length of butt-welded seams (longitudinal and circumferential and intersections) in furnaces and reversal chamber wrapper plates shall be non-destructively tested by radiographic and/or ultrasonic techniques.

5.5.5.6 Branch welds and fillet welds

For branch welds and fillet welds welded to the same procedure, 10 % of the total length of welding shall be non-destructively tested when the thickness of the parts being joined exceeds 30 mm. For branch welds and fillet welds where the parts being joined are less than 30 mm thick, 5 % of the total length of welding shall be so examined.

The location of the weld to be non-destructively tested shall be selected at random by the inspecting authority. If any of the welds of the same type tested are found to be unsatisfactory, the extent of the non-destructive testing shall be increased at the discretion of the inspecting authority.

The non-destructive techniques employed shall be magnetic particle or liquid penetrant except in the case of branch welds when the thickness of the parts being joined exceeds 30 mm, in which case ultrasonic techniques shall be used.

For a given piece of equipment, the branch welds and fillet welds shall be tested as for the main welds (10 % or 100 %) if their diameter is greater than 500 mm.

5.6 Openings in or adjacent to welds

Openings in or adjacent to welded seams should be avoided especially when this seam is not stress relieved. The minimum distance from the centre-line of the welded seam to the nearest point of the weld of the connection, or edge of the opening, should be 60 mm, or four times the shell plate thickness, whichever is the larger.

Where this is not possible, it is recommended that the opening crosses the welded seam completely and in such a manner that the tangent at the point where the axis of the seam meets the edge of the opening makes an angle with this axis as close as possible to 90°. In this case the welded seam shall be non-destructively tested for a length of 60 mm, or four times the shell plate thickness, whichever is the larger, at each side of the opening.

5.7 Fillet welds

5.7.1 Fillet welds may be employed as strength welds for pressure parts within the limitations as indicated in annex B. In order to ensure complete fusion at the root of the fillet welds, particular care shall be taken in the layout of joints with fillet welds.

5.7.2 Corner or T-joints may be made with fillet welds provided that the plates are properly supported independently of such welds, except that independent supports are not required for joints such as lugs for platforms, ladders and other similar attachments.

5.8 Fabrication

5.8.1 General

The weld quality shall be in accordance with the requirements of this International Standard. The methods of welding main seams shall provide full penetration, and it shall be demonstrated by qualification tests that the welding method can produce a weld that is free from significant defects.

Preheating shall be provided in accordance with table 8.

In the case of high carbon steels, and also for thick plates, preheating and inspection for cracks may be necessary (see also 2.6.1).

Table 8 — Recommended preheating temperatures for welding of plates, sections, bars and forgings

Type	Hydrogen controlled weld metal		Non-hydrogen controlled weld metal	
	Material thickness ¹⁾ mm	Minimum pre-heating temperature °C	Material thickness ¹⁾ mm	Minimum pre-heating temperature °C
Carbon and carbon manganese steel, ≤ 0,25 % C	≤ 30	5	≤ 20	5
	> 30	100	> 20 ≤ 50 ²⁾	100
1) The greatest component thickness at the joint. 2) It is recommended that only hydrogen controlled weld metal is used for thicknesses greater than 50.				

5.8.2 Welding processes

Details of welding processes are not defined herein. Any process is acceptable provided that the requirements of the procedure qualification tests are met.

5.8.3 Welding procedure qualification

5.8.3.1 Procedure agreement

The welding procedures used by the manufacturer shall have been certified by the inspector or the inspecting authority in accordance with the requirements of this International Standard. Previous qualification of procedures in accordance with the appropriate national standards may be accepted in lieu by agreement with the inspecting authority.

5.8.3.2 Test welds

All test welds for welding procedure qualifications shall be carried out as butt welds.

If the production welding is to be done in the flat position, the procedure test plate shall also be welded in the flat position. If the production welding is to be done in any other position, the procedure test weld shall be welded in a similar position. All positions falling within the limits of any fundamental welding position as established by ISO 6947 are regarded as similar positions.

For fillet welds, a more representative testing shall be applied, if thought necessary, by agreement between manufacturer, purchaser and inspecting and/or regulating authority.

5.8.3.3 Requirements

Apart from the requirements specified in 5.8.3.1 and 5.8.3.2, procedure qualification test welds for all pressure parts of pressure vessels, including pipes and tubes, shall be made in such a manner that the welds can be considered representative of those made in production, taking into account the following particulars.

a) Type of base metal

The procedure qualification test plates or test pipes shall be made from steel with a tensile strength in the same range as that of the steel to be used in the construction, and having a chemical composition approximately corresponding, in so far as practicable, to the most unfavourable analysis from the standpoint of weldability and within the limits of the material specification of the steel concerned.

b) Electrodes, filler material, flux and arc shielding gas

Welding filler materials, i.e. electrodes as well as combinations of wire, powder and shielding gas combinations, shall be to the same standard or manufacturing specification, for both the procedure qualification and the production welds.

c) Type of joint preparation

Subject to agreement with the inspecting authority, a change of joint preparation for hand welding may be made without further testing. For semi-automatic or automatic processes, any substantial change in plate edge preparation will require a further test.

d) Welding technique

A new procedure qualification test is required in the following cases: