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Unfired pressure vessels

Part 101: Example of application

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The UK participation in its preparation was entrusted to Technical Committee PVE/1, Pressure Vessels.

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

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ISBN 978 0 580 87642 4

ICS 23.020.30

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 September 2015.

Amendments issued since publication

Date	Text affected

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TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 13445-101

April 2015

ICS 23.020.30

English Version

Unfired pressure vessels - Example of application

Récipients sous pression non soumis à la flamme - Partie 101 : Exemple d'application

Unbefeuerte Druckbehälter - Teil 101: Anwendungsbeispiel

This Technical Report was approved by CEN on 10 February 2015. It has been drawn up by the Technical Committee CEN/TC 54.

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Foreword

This document (CEN/TR 13445-101:2015) has been prepared by Technical Committee CEN/TC 54 “Unfired pressure vessels”, the secretariat of which is held by BSI.

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1 Scope

This Technical Report presents an application of EN 13445 through an example of design and fabrication of an unfired pressure vessel. Every step is described as far as possible:

— Material choice;

— Design and calculation;

— Fabrication;

— Inspection and testing;

using the following part of EN 13445:

— EN 13445-1:2009;

— EN 13445-2:2009;

— EN 13445-3:2009;

— EN 13445-4:2009;

— EN 13445-5:2009 .

As applicable, some choices for design or fabrication are made according to “the state of art” practice.

Some parts of EN 13445 are reproduced in order to show which requirements are relevant to the design and fabrication of the target vessel.

2 Normative references

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

EN 287-1:2004+A2:2006, *Approval testing of welders — Fusion welding — Part 1: Steels*

EN 473:2008, *Non-destructive testing — Qualification and certification of NDT personnel — General principles*

EN 764-5:2002, *Pressure Equipment — Part 5: Compliance and Inspection Documentation of Materials*

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

EN 1418:1997, *Welding personnel — Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials*

EN 1515-3:2005, *Flanges and their joints — Bolting — Part 3: Classification of bolt materials for steel flanges, class designated*

EN 1515-4:2009, *Flanges and their joints — Bolting — Part 4: Selection of bolting for equipment subject to the Pressure Equipment Directive 97/23/EC*

EN 1759-1:2004, *Flanges and their joint — Circular flanges for pipes, valves, fittings and accessories, Class designated — Part 1: Steel flanges, NPS 1/2 to 24*

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EN 10025-2:2004, *Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels*

EN 10028-1:2007, *Flat products made of steels for pressure purposes — Part 1: General requirements*

EN 10028-2:2003, *Flat products made of steels for pressure purposes — Part 2: Non-alloy and alloy steels with specified elevated temperature properties*.

EN 10029:2010, *Hot-rolled steel plates 3 mm thick or above —Tolerances on dimensions and shape*

EN 10204:2004, *Metallic products — Types of inspection documents*.

EN 10216-3:2002, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 3: Alloy fine grain steel tubes*

EN 10222-4:1998, *Steel forgings for pressure purposes — Part 4: Weldable fine grain steels with high proof strength*.

EN 10269:1999+A1:2006, *Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties*

EN 12560-4:2001, *Flanges and their joints — Gaskets for Class-designated flantes — Part 4: Corrugated, flat or grooved metallic and filled metallic gaskets for use with steel flanges*

CR ISO 15608:2000, *Welding — Guidelines* for a metallic material grouping system *(ISO/TR 15608:2000)*

EN ISO 15614-1:2004, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (ISO 15614-1:2004)*

3 Presentation of example

3.1 General

The target vessel consists of several components:

— a cylindrical shell,

— two elliptical ends,

— a welding neck flange,

— a nozzle,

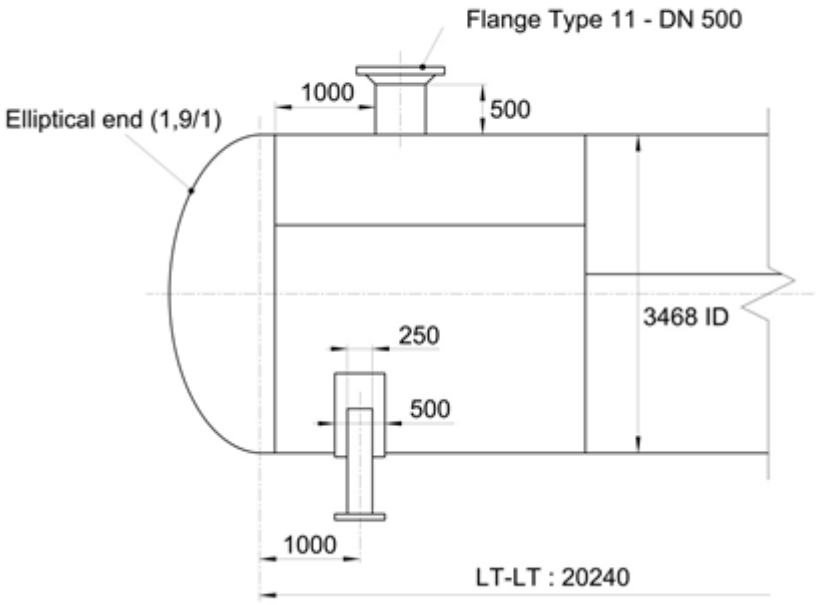
— two saddle supports arranged symmetrically

3.2 Pressure vessel data

The data specified for the present example are the following:

— Vessel data:

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Key

D_i = 3 468 mm

L = 20 000 mm (cylindrical shell length)

Figure 1 — Pressure vessel data

Material: steel

— Service data:

Normal service conditions:

— Internal pressure: 44 bar

— Maximum temperature: 50 °C

— Minimum metal temperature: -20 °C

— Liquid group 1, density: 0,54

— Pressure loading predominantly of non-cyclic nature

There are not exceptional service conditions.

PED 97/23/CE regulation applies.

The calculation of all components is performed by formulas (DBF: Design By Formula). According to the specified operating conditions, the pressure vessel is neither subjected to fatigue nor to creep.

It is supposed that there is only a risk of atmospheric corrosion during operation of the vessel. Thus, a corrosion allowance of 3 mm is added.

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3.3 PED 97/23/CE Category

The maximum allowable pressure *PS* used as a first approach is 44 bar and the fluid is a liquid of group 1.

The category which applied for the target vessel is category II as defined in Clause 3 paragraph 1.1(b) of the PED which indicates the use of Table 3 of Annex II of PED to set the category.

3.4 Extracts from EN 13445-1 to EN 13445-5:2009 and from others standards

The extracts from the EN 13445 Standard clauses which are the most relevant at each step of the example are reproduced in black frames. When necessary, the adequate requirements in these extracts are framed in red.

Other extracts of standards referenced in EN 13445 are reproduced, also in black frames, and the standard from which they are extracted is mentioned. When necessary, the adequate requirements in these extracts are framed in red.

4 Materials

4.1 General

EN 13445-2:2009 gives the minimum requirements to be fulfilled for steel entering the manufacturing of pressure vessel. The informative Annex E of this standard references European materials usable for pressure vessel manufacturing. The corresponding steel grades come from harmonized European standards. The Grouping according to CEN ISO/TR 15608:2000 is also given for each grade.

The minimum requirements concern elongation, impact test and chemical composition. These requirements for steel should ensure toughness and good behaviour of materials during manufacturing (weldability and forming).

Table 4.1-1 of this report summarizes some properties of the materials which have been chosen for fabrication of the target vessel. This table shows how the requirements of EN 13445-2:2009 are fulfilled.

4.2 Minimum requirements for materials

4.2.1 General

The following clauses of EN 13445-2:2009 shall be fulfilled:

4.2.2 Minimum elongation

The requirements for minimum elongation are fulfilled by the chosen materials, see Table 4.1-1.

4.1.4 Steels shall have a specified minimum elongation after fracture measured on a gauge length

$$L_o = 5{,}65\sqrt{S_o} \qquad (4.1\text{-}1)$$

where

S_o is the original cross sectional area within the gauge length.

The minimum elongation after fracture in any direction shall be ≥ 14 %;

However, lower elongation values may also be applied (e.g. for fasteners or castings), provided that appropriate measures are taken to compensate for these lower values and the specific requirements are verifiable.

Figure 2 — Abstract from EN 13445-2:2009

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4.2.3 Impact test for ferritic steel

The requirements for impact test are fulfilled by the chosen materials, see Table 4.1-1. Requirements of Annex B of EN 13445-2:2009 shall also apply; see 4.5 of this report.

> **4.1.6** Steels shall have a specified minimum impact energy measured on a Charpy-V-notch impact test specimen (EN 10045-1:1990) as follows:
>
> — ≥ 27 J for ferritic and 1,5 % to 5 % Ni alloy steels;
>
> — ≥ 40 J for steels of material group 8, 9.3 and 10
>
> at a test temperature in accordance with Annex B, but not higher than 20 °C. The other requirements of Annex B shall also apply.

Figure 3 — Abstract from EN 13445-2:2009

4.2.4 Chemical composition of selected grade

The requirements for chemical composition are fulfilled by the chosen materials, see Table 4.1-1, except for the bolting grade *42CrMo4* (1.7225), but this product is not intended for welding or forming as stated in 4.1.7 of EN 13445-2:2009. Indeed, following EN 10269:1999, EN 10269:1999+A1:2006, the specified chemical composition for this grade of bolting is:

— %C: 0,38 to 0,45;

— % P: 0,035 max;

— % S: 0,035 max.

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4.1.7 The chemical composition of steels intended for welding or forming shall not exceed the values in Table 4.1-1. Line 2 of the table refers to vessels or parts designed using Design by Analysis – Direct Route according to Annex B of EN 13445-3:2009. Exceptions shall be technically justified.

Table 4.1-1 — Maximum carbon-, phosphorus- and sulphur contents for steels intended for welding or forming

Steel group (according to Table A-1)	Maximum content of cast analysis		
	% C	% P	% S
Steels (1 to 6 and 9)	0,23[a]	0,035	0,025
Steels (1 to 6 and 9) when DBA – Direct Route is used [c]	0,20	0,025	0,015
Ferritic stainless steels (7.1)	0,08	0,040	0,015
Martensitic stainless steels (7.2)	0,06	0,040	0,015
Austenitic stainless steels (8.1)	0,08	0,045	0,015[b]
Austenitic stainless steels (8.2)	0,10	0,035	0,015
Austenitic-ferritic stainless steels (10)	0,030	0,035	0,015

[a] Maximum content of product analysis 0,25 %.
[b] For products to be machined a controlled sulphur content of 0,015 % to 0,030 % is permitted by agreement provided the resistance to corrosion is satisfied for the intended purpose.
[c] In addition the ratio on thickness reduction (ratio of initial thickness of slab/ingot to the thickness of the final plate) shall be equal or greater than:
— 4 for NL2 steels and steels of material group 9;
— 3 for other materials.

Figure 4 — Abstract from EN 13445-2:2009

4.3 Mechanical properties of the chosen materials

The selected grades and their appropriate properties are summarized in Table 4.1-1.

All the mechanical properties presented in this table are minimum values from transversal specimen and are specified in the relevant technical specification. Transversal specimens are defined as specimen taken in a direction perpendicular to the direction of principal deformation of the product (e.g. for flat products the transversal direction is perpendicular to the rolling direction).

Since the minimum yield strength and tensile strength values are specified in the material technical specification as a function of the product thickness the values to be used for the design of each specific component are not known at first. They can be set only once the design calculations performed according to the relevant EN 13445-3:2009 rules have shown that the thickness assumed for calculation is acceptable. In some cases an iteration on the thickness and the corresponding mechanical properties is necessary to get the correct values (see Clause 5 of this report).

For determination of the material characteristics above 20 °C, the interpolation rules which apply are those defined in 4.2.2 of EN 13445-2:2009:

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4.2.2 Design temperature above 20 °C

4.2.2.1 A material shall only be used for pressure parts within the range of temperatures for which the material properties required by EN 13445-3:2009 are defined in the technical specification for the material. If the technical delivery condition does not contain the specific material values required for the allowable temperature TS the values required in EN 13445-3:2009 for the design shall be determined by linear interpolation between the two adjacent values. Values shall not be rounded up.

For other than austenitic and austenitic-ferritic stainless steels, the specified value of R_{eH} ($R_{p0,2}$) at room temperature (RT) may be used for temperatures less than or equal to 50 °C. Interpolation between 50 °C and 100 °C shall be performed with the values of RT and 100 °C and using 20 °C as the starting point for interpolation. Above 100 °C linear interpolation shall be performed between the tabulated values given in the table.

Figure 5 — Abstract from EN 13445-2:2009

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Table 4.1-1

Component	**Standard(s)**	**Grades (Steel Number)**	**Specified minimum yield strength at room temperature Rp0,2 (MPa)**	**Specified minimum yield strength at 50 °C Rp0,2/t (MPa)**	**Specified minimum tensile strength at room temperature Rm (MPa)**	**Specified minimum elongation after fracture A%** (EN 13445-2:2009, 4.1.4)	**Impact energy *KCV*** (EN 13445-2:2009, 4.1.6)	**Heat treatment condition**	**Classification according to CR** ISO 15608:2000
Cylindrical shell	EN 10028-2:2003	P295GH (1.0481)	285	276	460	21	27 J @ -20 °C	+N	1.2
Elliptical end	EN 10028-2:2003	P295GH (1.0481)	285	276	460	21	27 J @ -20 °C	+N	1.2
Nozzle	EN 10216-3:2002	P275NL2 (1.1104)	275	EN 13445-2:2009, 4.2.2	390	22	47 J @ -20 °C	+N	1.1
Flange	EN 1759-1:2004 EN 10222-4:1998	P285QH (1.0478)	255	EN 13445-2:2009, 4.2.2	390	23	27 J @ -20 °C	+QT	1.2
Bolting	EN 10269:1999	42CrMo4 (1.7225)	730	720	860	14	40 J @ -40 °C	+QT	3.2
Reinforcing plate	EN 10028-2:2003	P295GH (1.0481)	285	276	460	21	27 J @ -20 °C	+N	1.2
Saddle support	EN 10025-2: 2004	S275J2 (1.0145)	275	No value	430	21	27 J @ -20 °C	+N	1.1

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4.4 Type of material certificate

4.4.1 PED requirements

Annex I paragraph 4.3 of the PED states that for the Category II main pressure-bearing parts of pressure equipment, the material certificate shall be a certificate of specific control. In accordance with EN 10204:2004, this certificate shall be, as a minimum, of type 3.1.

4.4.2 Type of certificate for pressure vessel components

Material certificate may be selected in accordance with EN 764-5:2002 which specifies the type of material certificate to obtain from the material producer following the considered part (main pressure-bearing parts, pressure parts other than main pressure-bearing parts or non pressure-bearing parts).

4.1.2 Materials for pressure-bearing parts compliant with the requirements of this European Standard shall be accompanied by inspection documents in accordance with EN 10204:2004. Certificate of specific control (3.1 or 3.2 certificate) shall be required for all steels if Design by Analysis – Direct Route according to Annex B of EN 13445-3:2009 is used.

NOTE The type of inspection document should be in accordance with EN 764-5:2002 and include a declaration of compliance to the material specification.

Figure 6 — Abstract from EN 764-5:2002

Figure 1 of EN 764-5:2002 below is useful to determine the type of certificate:

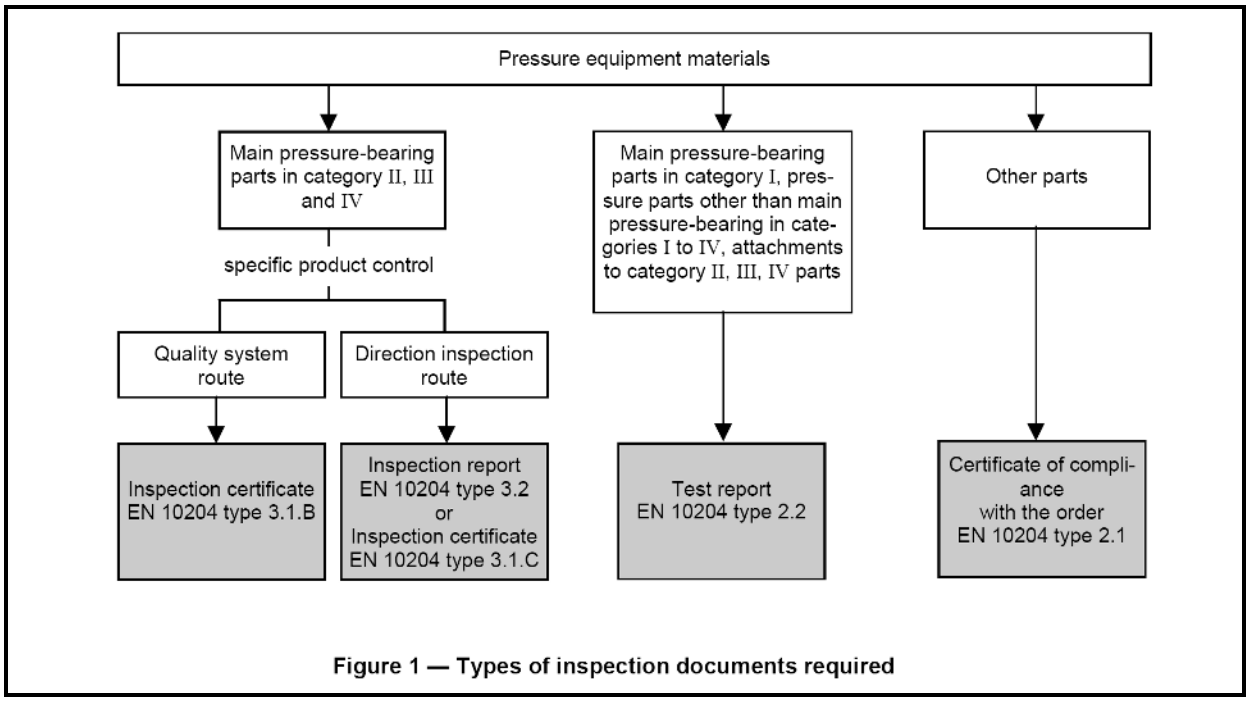


Figure 1 — Types of inspection documents required

NOTE Edition of EN 10204:1991 is used for application of EN 764-5:2002 and edition of EN 10204:2004 is used for application of EN 13445-2:2009. Type 3.1B of EN 10204:1991 is replaced by 3.1 of EN 10204:2004. Types 3.1A and 3.1C is replaced by 3.2 of EN 10204:2004.

Figure 7 — Abstract from EN 764-5:2002

Table 4.4.2-1 below summarizes the type of material certificate according to EN 764-5:2002:

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Table 4.4.2-1

Components	Type of components	Minimum type of certificate according to EN 10204:2004
Cylindrical shell	Main pressure-bearing parts	3.1 (3.1B as defined in EN 10204:1991)
Elliptical end	Main pressure-bearing parts	3.1 (3.1B as defined in EN 10204:1991)
Nozzle	Pressure part other than main pressure-bearing parts	2.2
Flange	Pressure part other than main pressure-bearing parts	2.2
Bolting	Pressure part other than main pressure-bearing parts	2.2
Reinforcing plate (for saddle support)	Non-pressure-bearing parts	2.2
Saddle support	Non-pressure-bearing parts	2.2

NOTE The type of certificate for the saddle support reinforcing plate could be of type 3.1 because the material grade is chosen for being the same as for the cylindrical shell. To manufacture the reinforcing plate, the vessel manufacturer could use a plate from the lot used to manufacture the cylindrical shell.

4.5 Prevention of brittle fracture

4.5.1 General

Annex B of EN 13445-2:2009 proposes three methods to prevent the risk of brittle fracture. The two first methods are applied to the target vessel. The last one, Method 3, is not used because it would need to perform a complete fracture mechanics analysis.

4.5.2 Method 1 (B.2.2 of EN 13445-2:2009)

4.5.2.1 General

As stated in B.2.2.1 of EN 13445-2:2009, Method 1 permits to select steels taken from harmonized European standards. The assumptions are that $T_R = T_{27J} = T_{KV}$ and the required toughness values shall be obtained after manufacturing.

4.5.2.2 Determination of test temperature T_{KV}

The Tables in B.2.2 give reference temperature T_R as a function of grade, reference thickness (depending on whether PWHT is performed or not). Corresponding table for each product shall apply for each type of products. Results corresponding to PWHT shall be taken into account (see 6.5.2 of this report):

— Plates and strip

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Table B.2–2 — General requirements for prevention of brittle fracture — Reference thicknesses for plates and strips

Plates and Strips								
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. reference thickness e_B mm AW	Max. reference thickness e_B mm PWHT	Design reference temperature T_R °C	Material group to CR ISO 15608:2000	Remarks
1	EN 10028-2:2003	P235GH	1.0345	35	200	– 20	1.1	
2		P265GH	1.0425	35	200			
3		P295GH	1.0481	35	110		1.2	
4		P355GH	1.0473	35	70			

Figure 8 — Abstract from EN 13445-2:2009

— Tubes

Table B.2–3 — General requirements for prevention of brittle fracture — Reference thicknesses for seamless and welded tubes

Seamless and welded tubes								
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. reference thickness e_B mm AW	Max. reference thickness e_B mm PWHT	Design reference temperature T_R °C	Material group to CR ISO 15608:2000	Remarks
231	EN 10216-3:2004	P275NL1	1.0488	35	100	– 40	1.1	a)
232		P275NL2	1.1104	35	100	– 50		a)
233		P355N	1.0562	35	70	– 20	1.2	
234		P355NH	1.0565	35	70	– 20		
235		P355NL1	1.0566	35	70	– 40		
236		P355NL2	1.1106	35	70	– 50		

Figure 9 — Abstract from EN 13445-2:2009

— Forgings

Table B.2–5 — General requirements for prevention of brittle fracture with reference thickness for forgings

Forgings								
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. ref.. thickness e_B AW	Max. ref.. thickness e_B PWHT	Design reference temperature T_R (°C)	Material group to CR ISO 15608:2000	Remarks
367	EN 10222-3:1998	13MnNi6-3	1.6217	35	70	– 60	9.1	
369		15NiMn6	1.6228	35	50	– 80	9.1	
378	EN 10222-4:1998	P285QH	1.0478	35	85	– 20	1.2	
380		P355QH	1.0571	35	60	– 20	1.2	
382		P420QH	1.8936	35	50	– 20	3.1	

Figure 10 — Abstract from EN 13445-2:2009

— Nuts and bolts

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Table B.2–9 — General requirements for prevention of brittle fracture with reference thickness for nuts and bolts, bolting material according to EN 10269:1999

Type of material	Thickness limitation	Impact test	T_M	Remark
1.4307, 1.4301, 1.4303, 1.4404, 1.4401, 1.4948, 1.4919, 1.4941, 1.4980 a)	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 4	– 196 °C	Verification required for diameter or thickness > 20mm
1.4429, 1.4910,	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 4	– 273 °C	Verification required for diameter or thickness > 20mm
1.5523, 1.1133 1.6563	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 7	– 20 °C	—
1.7218	$d \leq 60$ mm	According to EN 10269:1999, Table 7	– 60 °C	—
	60 < $d \leq 100$ mm		– 50 °C	
1.6582, 1.6580, 1.7225	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 7	– 40 °C	—

Figure 11 — Abstract from EN 13445-2:2009

4.5.3 Method 2 (Clause B.2.3 of EN 13445-2:2009)

4.5.3.1 General

Method 2 may be used to derive a reference temperature T_R that is lower than the one derived from Method 1.

4.5.3.2 Definitions

The following definitions are given by EN 13445-2:2009 and apply:

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3.1.3
design reference temperature T_R
the temperature used for determining the impact energy requirements and is determined by adding the temperature adjustment T_S to the minimum metal temperature T_M:

$$T_R = T_M + T_S$$

3.1.4
impact test temperature T_{KV}
the temperature at which the required impact energy has to be achieved (see clause B.2).

3.1.5
impact energy KV
the energy absorbed by a sample of material when subjected to a Charpy-V-notch test in accordance with EN 10045-1:1990

3.1.6
reference thickness e_B
thickness of a component to be used to relate the design reference temperature T_R of the component with its required impact test temperature T_{KV} , (see Tables B.2-2 to B.2-7 and Figures B.2-1 to B.2-11). For unwelded parts the reference thickness e_B is equal to the nominal wall thickness (including corrosion allowance). For welded parts the reference thickness is defined in Table B.4-1.

Figure 12 — Abstract from EN 13445-2:2009

4.5.3.3 Impact energy requirements

Table B.2-13 gives also the required impact energy *KV* on a 10 mm x 10 mm test piece, *KV* = 27 J. The parent material, heat affected zone and welds shall meet this impact energy at the impact test temperature T_{KV} derived from Method 2.

Table B.2–13 — Impact energy requirements for C, CMn, fine grain steels, Ni-alloyed steels with not more than 1,5 % Ni

Specified minimum yield strength of base material MPa	Required impact energy KV (on 10 mm × 10 mm test pieces) J min	Figure defining required T_{KV}	
		Non welded or post-weld heat treated	As welded
$R_e \leq 275$	27	B.2-1	B.2-2
$R_e \leq 355$	27	B.2-3	B.2-4
$R_e \leq 460$	40	B.2-5	B.2-6
$R_e \leq 500$	40	B.2-7	B.2-8

Figure 13 — Abstract from EN 13445-2:2009

4.5.3.4 Determination of the test temperature T_{KV}

4.5.3.4.1 Components and welded joints

A PWHT is applied for some welded joints as described in 6.5.2.1 of this report.

The reference temperature is defined as being $T_R = T_M$ = -20 °C.

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Diagrams permit the determination of the impact test temperature T_{KV}. The relevant ones shall be selected from Table B.2-13 of EN 13445-2: 2009 here-above.

The reference thickness e_B is determined from Table B.4-1 of EN 13445-2:2009. The way to obtain T_{KV} from the values of T_R and e_B in the relevant diagram is illustrated for each construction detail of the target vessel in Table 4.5.3.4.1-1 to Table 4.5.3.4.1-4 of this report.

There is no construction detail applying to longitudinal seam welds and to circumferential seam welds in the cylindrical shell. In other words, the construction detail No.1 does not apply because it makes reference to butt welded components of unequal thickness.

Therefore, for these welded joints, the reference thickness e_B is equal to the nominal thickness of the component, i.e. 45 mm.

Then, Figure B.2-3 of EN 13445-2:2009 applies to derive T_{KV} (see Table 4.5.3.4.1-1 below).

Table 4.5.3.4.1-1 — Longitudinal and circumferential seam welds in cylindrical shell

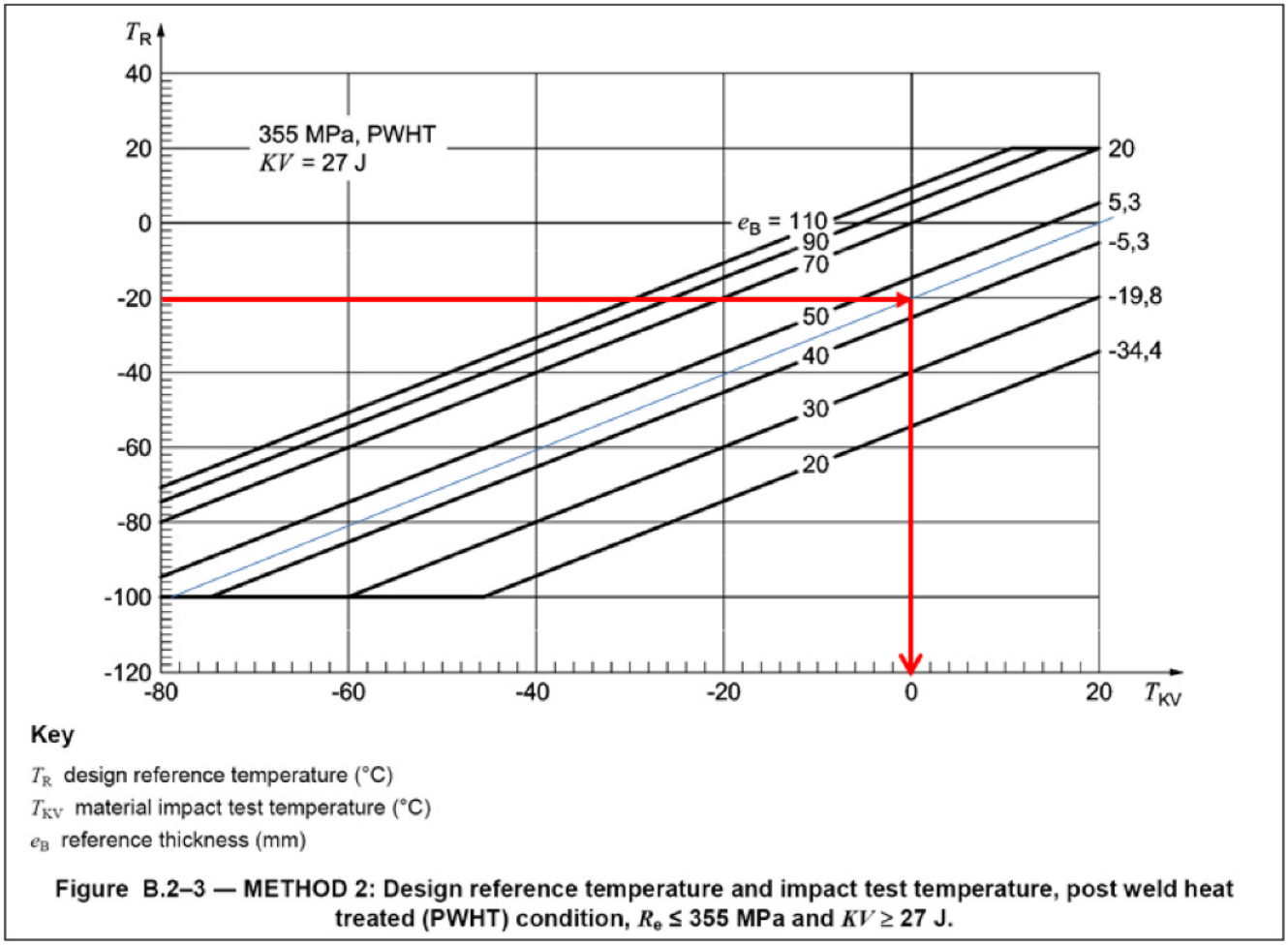
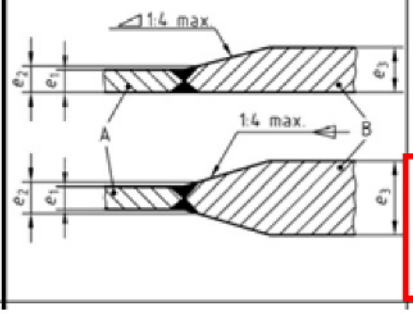


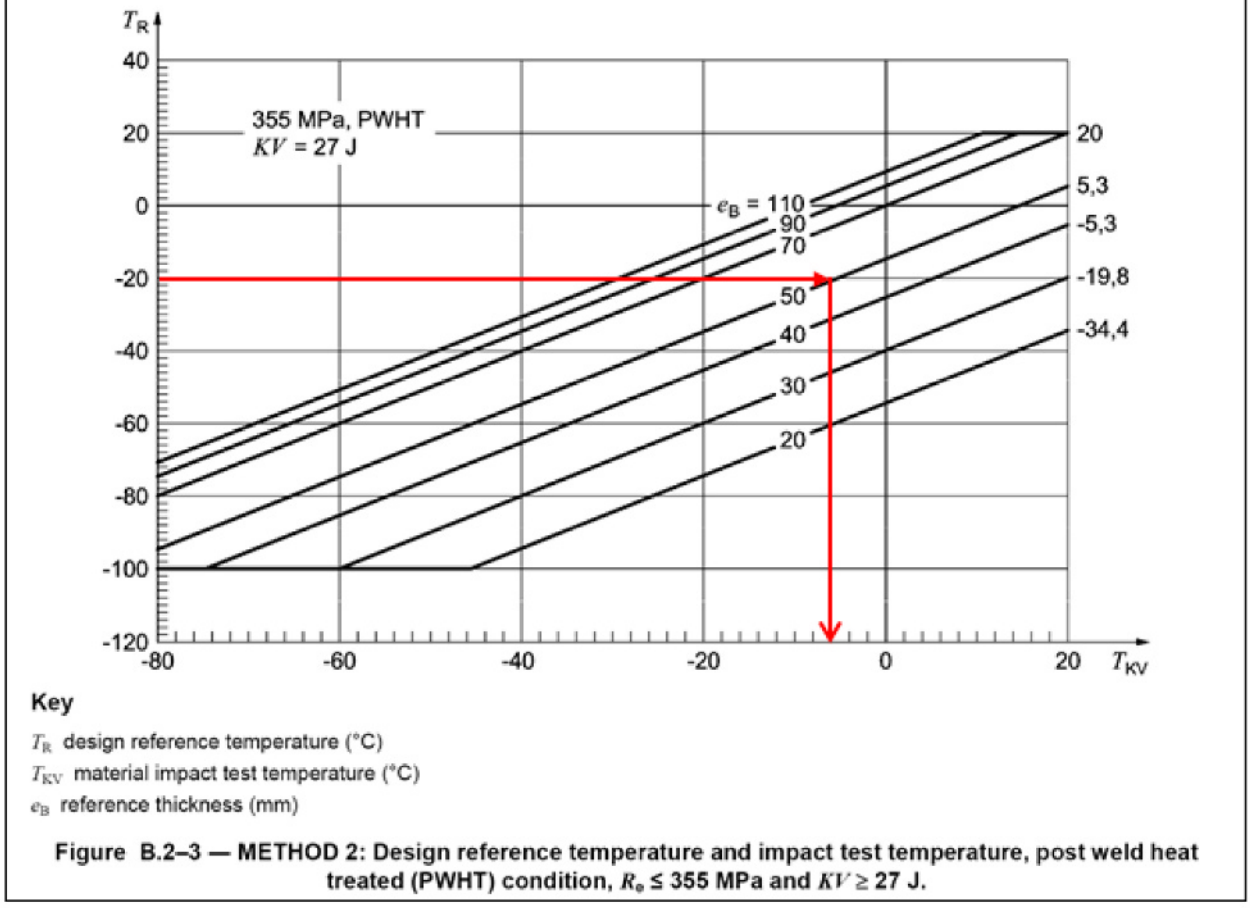
Figure B.2–3 — METHOD 2: Design reference temperature and impact test temperature, post weld heat treated (PWHT) condition, $R_e \leq 355$ MPa and $KV \geq 27$ J.

Figure 14 — Abstract from EN 13445-2:2009

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Table 4.5.3.4.1-2 — Base material of cylindrical shell and elliptical end – Circumferential joint between cylindrical shell and elliptical end

1	Butt welded components of unequal thickness 	AW	e_1	e_2	e_2 check e_3 in Figures B.2–2, B.2–4, B.2–6, B.2–8
		PWHT	e_1	e_2	e_3



Key

T_R design reference temperature (°C)
T_{KV} material impact test temperature (°C)
e_B reference thickness (mm)

Figure B.2–3 — METHOD 2: Design reference temperature and impact test temperature, post weld heat treated (PWHT) condition, $R_e \leq 355$ MPa and $KV \geq 27$ J.

Figure 15 — Abstract from EN 13445-2:2009

The reference thickness e_B is determined as follows:

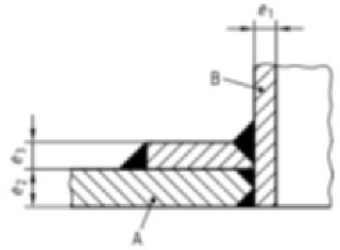
— For the cylindrical shell, e_B is defined by Part A and is referenced as e_1 (T_{KV} is equal to 0 °C, see Table 4.5.3.4.1-1 of this report).

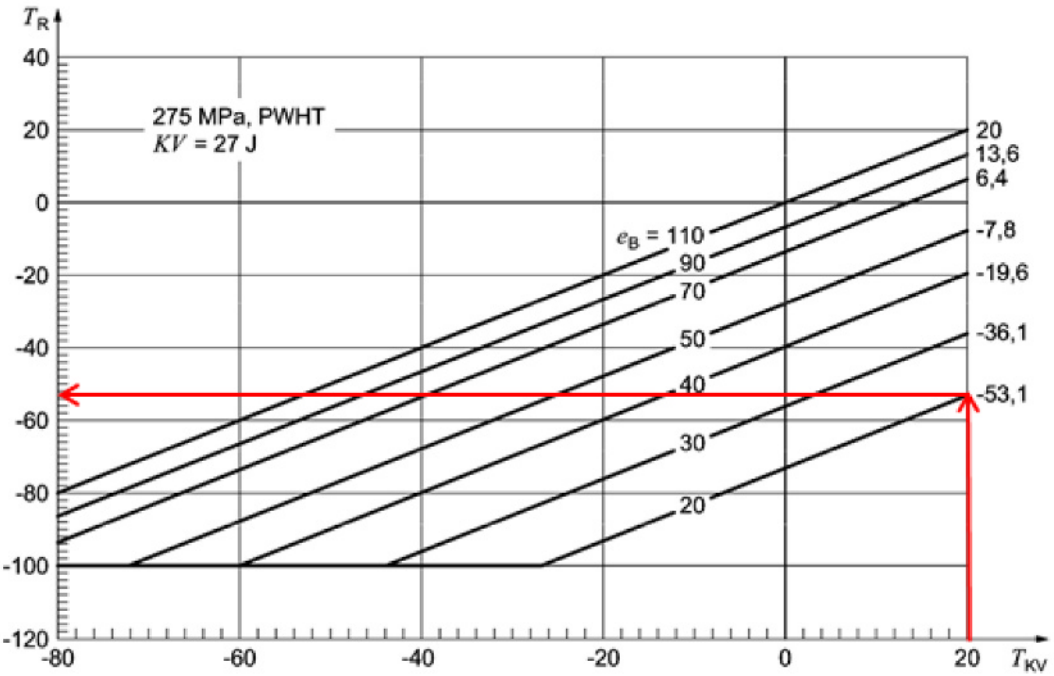
— For the elliptical end, e_B is defined by Part B and is referenced as e_3. The diagram used is the one of Figure B.2-3 (T_{KV} is equal to -6 °C, see Table 4.5.3.4.1-2 above).

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— For the weld, e_B is referenced as e_2 and is taken as equal to 50 mm to be conservative. The diagram used is the one of Figure B.2-3 (see Table 4.5.3.4.1-2 above).

Table 4.5.3.4.1-3 — Construction detail for the branch

3		AW	e_2	e_2 or e_3, if thicker	e_1
		PWHT	e_2	e_2 or e_3, if thicker	e_1



Key

T_R design reference temperature (°C)
T_{KV} material impact test temperature (°C)
e_B reference thickness (mm)

Figure B.2–1 — METHOD 2: Design reference temperature and impact test temperature, post weld heat treated (PWHT) condition, for $R_e \leq 275$ MPa and $KV \geq 27$ J.

Figure 16 — Abstract from EN 13445-2:2009

The reference thickness e_B is determined as follows:

— For the cylindrical shell, e_B is defined by Part A and is referenced as e_2; the diagram used to determine the impact test temperature T_{KV} for the cylindrical is that of Figure B.2-3 of EN 13445-2:2009 ($R_e \leq 355$ MPa, see Table 4.5.3.4.1-1 of this report).

— For the nozzle, e_B is defined by Part B and is referenced as e_1, Figure B.2-1 (see Table 4.5.3.4.1-3 of this report) of EN 13445-2:2009 shall be used.

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— For the weld, e_B is referenced as e_2 or e_3 (the thickness of the cylindrical shell and of the reinforcing plate is the same) and the diagram used to determine the impact test temperature T_{KV} for the weld is that of Figure B.2-3 of EN 13445-2:2009 ($R_e \leq 355$ MPa, see Table 4.5.3.4.1-1 of this report).

For the nozzle (Part B), e_B is less than 20 mm, B.2.3.2 of EN 13445-2:2009 shall apply:

B.2.3.2 Procedure for base material less than 10 mm thick

T_R values and T_{KV} values shall be in accordance with Figures B.2–1 to B.2–11. The impact energy requirements are as specified in Tables B.2–13 and B.2–14.

For wall thicknesses < 20 mm the curve for 20 mm shall be used.

The required energies for the sub-sized specimens are given in Table B.3–1.

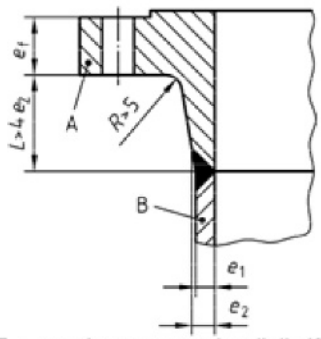
Figure 17 — Abstract from EN 13445-2:2009

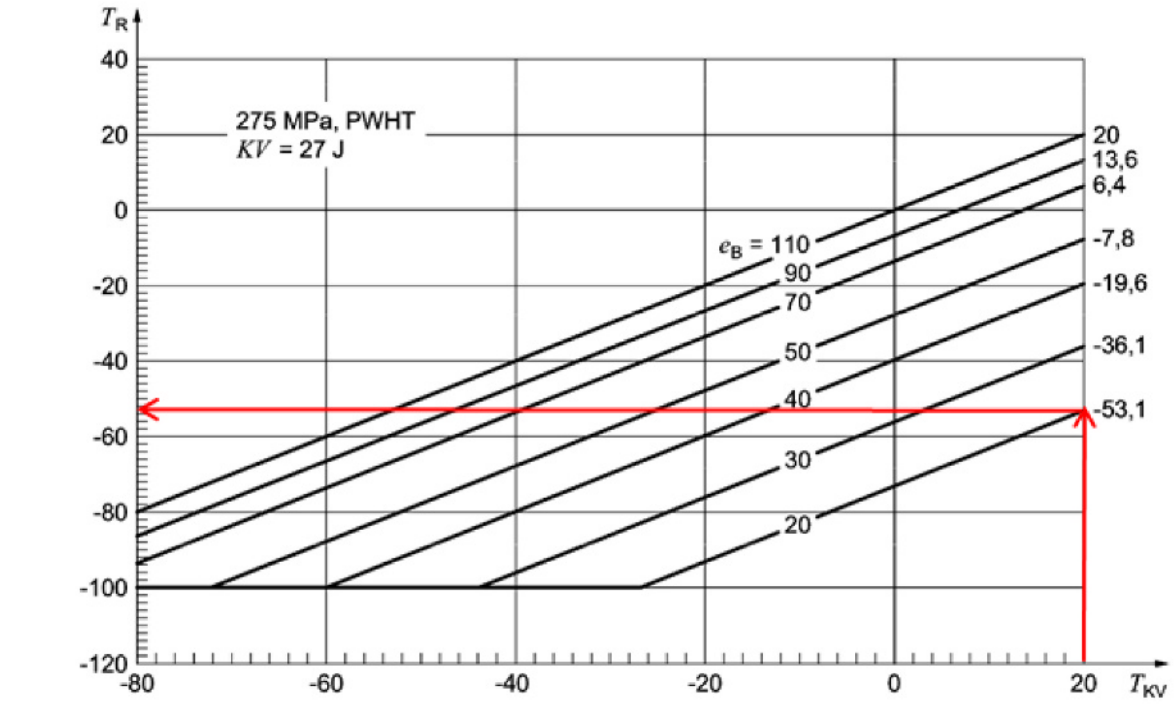
It is not possible to determine T_{KV} from T_R because the intersection point with the curve for 20 mm falls outside the diagram.

If one assumes an impact test temperature T_{KV} = 20 °C, the permitted T_R is -53,1 °C which is below the reference temperature of the target vessel (-20 °C). Thus, the considered T_{KV} value is confirmed and is equal to 20 °C.

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Table 4.5.3.4.1-4 — Construction detail for the welding neck flange and the nozzle

10	Forged or cast welding neck flanges [c]  NOTE e_f may be measured radially if that gives an advantage	AW	e_2 [a] check $e_f/4$ in Figures B.2–1, B.2–3, B.2–5, B.2–7 [a]	e_2	e_1
		PWHT	e_2 or $e_f/4$, if thicker	e_2	e_1



Key

T_R design reference temperature (°C)
T_{KV} material impact test temperature (°C)
e_B reference thickness (mm)

Figure B.2–1 — METHOD 2: Design reference temperature and impact test temperature, post weld heat treated (PWHT) condition, for $R_e \leq 275$ MPa and $KV \geq 27$ J.

Figure 18 — Abstract from EN 13445-2:2009

The reference thickness e_B is determined as follows:

— For the flange, e_B is defined by Part A and shall be the one determined from the requirement given by the Note *a* of the Table B.4-1 of EN 13445-2:2009:

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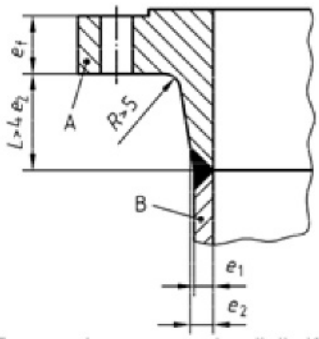
[a] The minimum test temperature of the two conditions: e_x (AW), e_y (PWHT or non-welded) shall be taken.

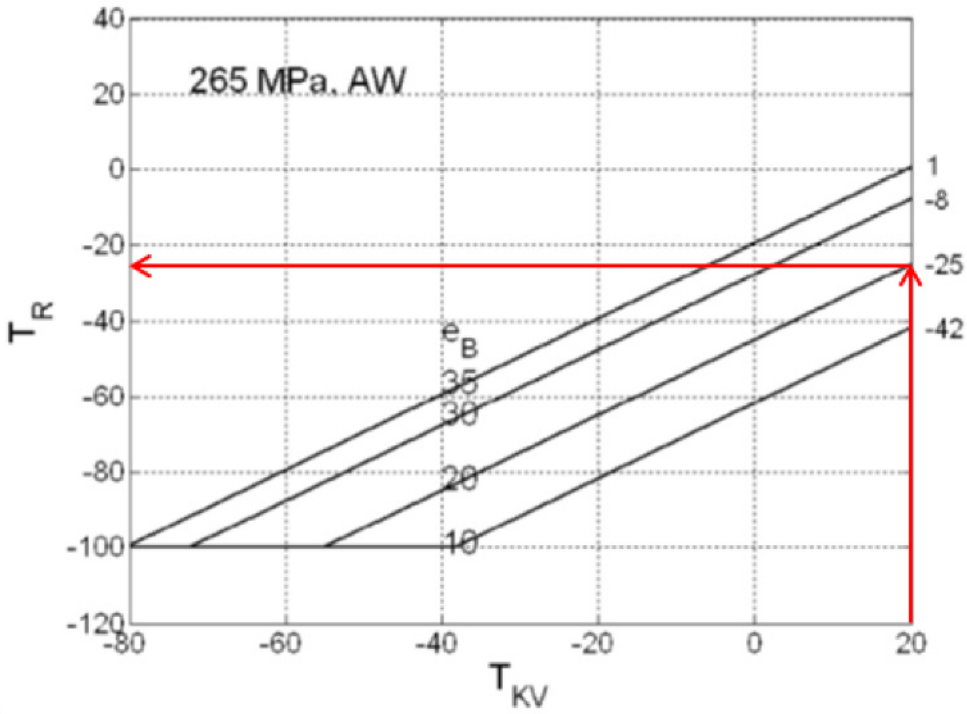
Figure 19 — Abstract from EN 13445-2:2009

Therefore, e_2 (12,5 mm) is applied to Figure B.2-2 for as-welded condition and $e_f/4$ (63,5 / 4 = 15,875 mm) is applied to Figure B.2-1 for non-welded condition (see Table 4.5.3.4.1-4 above).

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Table 4.5.3.4.1-4 — Construction detail for the welding neck flange and the nozzle *(continued)*

10	Forged or cast welding neck flanges [c]  NOTE e_f may be measured radially if that gives an advantage	AW	e_2 [a] check $e_f/4$ in Figures B.2–1, B.2–3, B.2–5, B.2–7 [a]	e_2	e_1
		PWHT	e_2 or $e_f/4$, if thicker	e_2	e_1



Key

T_R design reference temperature
T_{KV} material impact test temperature
e_B reference thickness

Figure B.2–2 — METHOD 2: Design reference temperature and impact test temperature as-welded (AW) condition, for $R_e \leq 265$ MPa and $KV \geq 27$ J

Figure 20 — Abstract from EN 13445-2:2009

— For the nozzle (Part B) e_B is referenced as e_1, the diagram used to determine the impact test temperature T_{KV} for the nozzle is the one of Figure B.2-1 (Re ≤ 275 MPa, see Table 4.5.3.4.1-3 of this report).

— For the weld, e_B is referenced as e_2, the diagram used to determine the impact test temperature T_{KV} is the one of Figure B.2-2 (Re ≤ 265 MPa, see Table 4.5.3.4.1-4 of this report).

In that case, all the reference thicknesses e_B are less than 20 mm, and B.2.3.2 of EN 13445-2:2009 shall apply:

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B.2.3.2 Procedure for base material less than 10 mm thick

T_R values and T_{KV} values shall be in accordance with Figures B.2–1 to B.2–11. The impact energy requirements are as specified in Tables B.2–13 and B.2–14.

For wall thicknesses < 20 mm the curve for 20 mm shall be used.

The required energies for the sub-sized specimens are given in Table B.3–1.

Figure 21 — Abstract from EN 13445-2:2009

It is not possible to determine T_{KV} from T_R because the intersection with the curve for 20 mm falls outside the diagrams.

If one assumes an impact test temperature T_{KV} = 20 °C, the permitted T_R for each part is the following:

— For the flange (Part A), two verifications shall be performed:

  — the one by using Figure B.2-2: T_R = -25 °C,

  — the other by using Figure B.2-1: T_R = -53,1 °C

— For the nozzle (Part B), by using Figure B.2-1: T_R = -53,1 °C

— For the weld, by using Figure B.2-2: T_R = -25 °C

Therefore, the reference temperature to retain is the greatest: T_R = -25 °C. This temperature is lower than the reference temperature of the target vessel (-20 °C). Thus, the considered T_{KV} value is confirmed and is equal to 20 °C.

4.5.3.4.2 Summary of T_{KV} applying to components and welded joints

The resulting T_{KV} for each component (base material) is summarized in Table 4.5.3.4.2-1 below:

Table 4.5.3.4.2-1 — T_{KV} for base material

Components	Construction details from Table B.4-1 of EN 13345-2:2009	e_B (mm)	T_{KV} (°C)
Cylindrical shell	1	e_1 = 45	0
Elliptical end	1	e_3 = 50	- 6
Nozzle	3 or 10	e_1 = 12,5	20
Flange	10	e_2 = 12,5 (as-welded condition, Note *a* of Table B.4-1 of EN 13445-2:2009 shall apply)	20

The resulting T_{KV} for each welded joint is summarized in Table 4.5.3.4.2-2 below:

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Table 4.5.3.4.2-2 — T_{KV} for welded joints

Components	Construction details from Table B.4-1 of EN 13345-2:2009	e_B (mm)	T_{KV} (°C)
Cylindrical shell to elliptical end	1	e_2 = 50	- 6
Branch and Nozzle	3	e_2 = 45	0
Flange to nozzle	10	e_2 = 12,5	20
Longitudinal seam welds in cylindrical shell	N/A	e_2 = 45	0
Circumferential seam welds in cylindrical shell	N/A	e_2 = 45	0

N/A: Non Applicable

For the material supplying, impact test temperature should be modified from the one given by the specification for material supplying. The base material T_{KV} values determined from the rules of Annex B of EN 13445-2:2009 should be specified.

For welded joints, see 6.2.3 of this report.

4.6 Particular Material Appraisal (PMA)

The pressure vessel manufacturer may use a material which is not issued from a European harmonized standard for main pressure bearing-parts as cylindrical shell and elliptical ends. For instance, manufacturer may use an ASME specification, e.g. SA 516 (2013 edition), which is the “Specification for pressure vessel plates, carbon steel, for moderate and lower temperature service”. The selected grade is the grade 70 which is non-alloyed steel. This specification should be used together with ASME SA-20 (2013 edition) which is the “Specification for general requirements for steel plates for pressure vessels”.

As a minimum, the following ordering information should be specified for mechanical test:

— Tension test following ASME SA 370 (2013 edition):
  — Minimum yield strength: 260 MPa,
  — Elongation:
    — in 8”: 17% minimum
    — in 2”: 21% minimum
  — Impact test following ASME SA 370 (striker radius of 8 mm):
  — 20 J (minimum average for three specimens) at -40 °C (for thicknesses over 25 mm to 50 mm includes) following ASME SA-20 (2013 edition)

Since ASME specification is not European harmonized standard and since there is not a European Approval of Materials (EAM) available, a Particular Material Appraisal (PMA) shall be provided by the manufacturer and requirements of Annex I paragraph 7.5 of PED 97/23/CE shall be fulfilled. In this case, mechanical test shall be the following:

— Tension test following EN ISO 6892-1:2009:
  — Minimum yield strength: 260 MPa,

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— Elongation with a length gauge of $5{,}65\sqrt{S_0}$ (S_o is the initial section of specimen):

— 14 % minimum

— Impact test following EN ISO 148-1:2010: (striker radius of 2 mm, an impact energy called KV_2 shall be specified):

— 27 J (minimum average for three specimens) at T_{KV} = 0 °C for the cylindrical shell and T_{KV} = -6 °C for the elliptical end as determined in 4.5.3.4 of this report

Moreover, a limitation of carbon content of 0,25 % can be applied, ASME SA 516 (2013 edition) specifying 0,28 % as a maximum for grade 70.

5 Calculations and design

5.1 General

In this Clause 5 of this report, design by formulas proposed by EN 13445-3:2009 will be used to determine the required thicknesses and therefore the nominal thicknesses of pressure vessel's components.

Verification of opening and of the resistance of the shell on two symmetrically saddle supports is also performed.

Normal operating load case and test load case are taken into account.

The reference number connected to each formula is the one used in EN 13445-3:2009. Therefore, it has no correspondence with Paragraph number of this report.

5.2 Definitions related to pressure

EN 13445-3:2009 gives definition about the pressures which are to be considered in calculation:

3.4
calculation pressure
differential pressure used for the purpose of the design calculations for a component
[EN 764-1:2004]

Figure 22 — Abstract from EN 13445-3:2009

3.10
design pressure
pressure at the top of each chamber of the pressure equipment chosen for the derivation of the calculation pressure of each component
[EN 764-1:2004]

Figure 23 — Abstract from EN 13445-3:2009

3.16
maximum permissible pressure
maximum pressure obtained from the design by formulae or relevant procedures of EN 13445-3:2009 for a given compoment in a given load case, or for the whole pressure vessel the minimum of these maximum permissible pressures of all compoments

Figure 24 — Abstract from EN 13445-3:2009

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For the target vessel, it is assumed that the design pressure P_d is equal to the calculation pressure P. Therefore $P = P_d = 44$ bar.

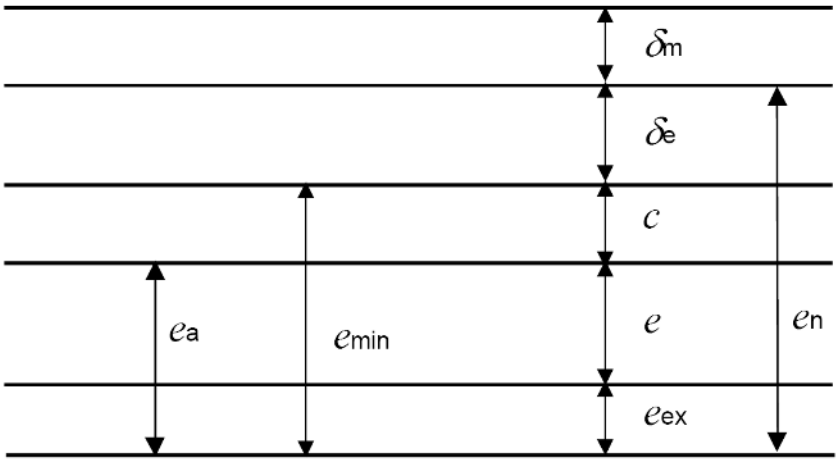
5.3 Thickness definitions and joint coefficient

5.3.1 Thicknesses

The definitions of the thicknesses are given in Clause 3 and also in 5.2.3 of EN 13445-3:2009 with Figure 5-1 which is reproduced below:

5.2.3 Inter-relation of thickness definitions

The inter-relation of the various definitions of thickness is shown in Figure 5-1.



Key

e is the required thickness;
e_n is the nominal thickness;
e_{min} is the minimum possible fabrication thickness ($e_{min} = e_n - \delta_e$);
e_a is the analysis thickness ($e_a = e_{min} - c$);
c is the corrosion allowance;
δ_e is the absolute value of the possible negative tolerance on the nominal thickness (e.g. taken from the material standards);
δ_m is the allowance for possible thinning during manufacturing process;
e_{ex} is the extra thickness to make up to the nominal thickness.

Figure 5-1 — Relationship of thickness definitions

Figure 25 — Abstract from EN 13445-3:2009

5.3.2 Joint coefficient

The value of the joint coefficient to be used for calculation of the required thickness of shells shall follow the requirement of 5.6 of EN 13445-3:2009.

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5.6 Joint coefficient

For the calculation of the required thickness of certain welded components (e.g. cylinders, cones and spheres), the design formulae contain z, which is the joint coefficient of the governing welded joint(s) of the component.

Examples of governing welded joints are:

— longitudinal or helical welds in a cylindrical shell;

— longitudinal welds in a conical shell;

— any main weld in a spherical shell/head;

— main welds in a dished head fabricated from two or more plates.

Figure 26 — Abstract from EN 13445-3:2009

The following welded joints are not governing welded joints:

— circumferential weld between a cylindrical or conical shell and a cylinder, cone, flange or end other than hemispherical;

— welds attaching nozzles to shells;

— welds subjected exclusively to compressive stress.

NOTE Circumferential joints may become governing joints due to external loads.

For the normal operating load cases, the value of z is given in Table 5.6-1. It is related to the testing group of the governing welded joints. Testing groups are specified in EN 13445-5:2009, Clause 6.

Table 5.6-1 — Joint coefficient and corresponding testing group

z	1	0,85	0,7
Testing Group	1, 2	3	4

In parent material, away from governing joints, z = 1.

For exceptional and testing conditions, a value of 1 shall be used, irrespective of the testing group.

Figure 27 — Abstract from EN 13445-3:2009

Then, the joint coefficient applies only to normal operating cases and, for the target vessel, only for longitudinal welds in cylindrical shell.

One assumes a fabrication with testing according to testing group 1. Accordingly, z = 1, (see 7.4.2 of this report).

5.4 Prevention of brittle fracture

Brittle fracture is prevented through the respect of the requirements of 5.4.8 of EN 13445-3:2009.

5.5 Maximum allowed values of the nominal design stress

The formulas for determination of the nominal design stresses are given in Table 6-1 of EN 13445-3:2009.

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