Closed expansion vessels with built in diaphragm for installation in water
National foreword

This British Standard is the UK implementation of EN 13831:2007. It supersedes BS 4814:1990 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee RHE/7, Expansion vessels using an internal diaphragm.

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

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

Compliance with a British Standard cannot confer immunity from legal obligations.

Amendments/corrigenda issued since publication

<table>
<thead>
<tr>
<th>Date</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 April 2008</td>
<td>Correction to supersession details</td>
</tr>
</tbody>
</table>

© BSI 2008

ISBN 978 0 580 62086 7
Closed expansion vessels with built in diaphragm for installation in water

This European Standard was approved by CEN on 26 July 2007.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>4</td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>1 Scope</td>
<td>6</td>
</tr>
<tr>
<td>2 Normative references</td>
<td>6</td>
</tr>
<tr>
<td>3 Terms and conditions</td>
<td>7</td>
</tr>
<tr>
<td>4 Symbols and units</td>
<td>9</td>
</tr>
<tr>
<td>5 Materials</td>
<td>10</td>
</tr>
<tr>
<td>5.1 General</td>
<td>10</td>
</tr>
<tr>
<td>5.2 Materials proven by experience and current use</td>
<td>10</td>
</tr>
<tr>
<td>5.3 Fasteners</td>
<td>11</td>
</tr>
<tr>
<td>5.4 Non-pressurised parts</td>
<td>11</td>
</tr>
<tr>
<td>6 Design and calculation</td>
<td>11</td>
</tr>
<tr>
<td>6.1 Design</td>
<td>11</td>
</tr>
<tr>
<td>6.1.1 Requirements pertaining to the diaphragm</td>
<td>11</td>
</tr>
<tr>
<td>6.1.2 Requirements pertaining to fresh water application</td>
<td>11</td>
</tr>
<tr>
<td>6.1.3 Outside finish</td>
<td>11</td>
</tr>
<tr>
<td>6.1.4 Inspection openings</td>
<td>11</td>
</tr>
<tr>
<td>6.1.5 Connections</td>
<td>12</td>
</tr>
<tr>
<td>6.1.6 Cleched joints</td>
<td>12</td>
</tr>
<tr>
<td>6.1.7 Volume tolerance of vessels</td>
<td>12</td>
</tr>
<tr>
<td>6.1.8 Fatigue</td>
<td>12</td>
</tr>
<tr>
<td>6.1.9 Loadings</td>
<td>13</td>
</tr>
<tr>
<td>6.2 Experimental design method</td>
<td>13</td>
</tr>
<tr>
<td>6.2.1 General</td>
<td>13</td>
</tr>
<tr>
<td>6.2.2 Preparations</td>
<td>13</td>
</tr>
<tr>
<td>6.2.3 Vessels with $PS \times V \leq 1\ 000 \text{ bar} \times L$</td>
<td>13</td>
</tr>
<tr>
<td>6.2.4 Vessels with $1\ 000 \text{ bar} \times L &lt; PS \times V &lt; 6\ 000 \text{ bar} \times L$</td>
<td>13</td>
</tr>
<tr>
<td>6.2.5 Vessel parts and components</td>
<td>13</td>
</tr>
<tr>
<td>6.3 Calculation method</td>
<td>14</td>
</tr>
<tr>
<td>6.3.1 General</td>
<td>14</td>
</tr>
<tr>
<td>6.3.2 Symbols</td>
<td>14</td>
</tr>
<tr>
<td>6.3.3 Cylindrical and spherical shells under internal pressure</td>
<td>15</td>
</tr>
<tr>
<td>6.3.4 Dished ends under internal pressure</td>
<td>15</td>
</tr>
<tr>
<td>6.3.5 Openings in cylindrical shells, spherical shells and dished ends</td>
<td>18</td>
</tr>
<tr>
<td>6.3.6 Bolted circular flat ends under internal pressure</td>
<td>25</td>
</tr>
<tr>
<td>6.3.7 Flanges and boltings</td>
<td>31</td>
</tr>
<tr>
<td>7 Manufacturing and welding</td>
<td>39</td>
</tr>
<tr>
<td>7.1 Introduction</td>
<td>39</td>
</tr>
<tr>
<td>7.2 General</td>
<td>39</td>
</tr>
<tr>
<td>7.3 Manufacturing tolerances</td>
<td>39</td>
</tr>
<tr>
<td>7.3.1 General</td>
<td>39</td>
</tr>
<tr>
<td>7.3.2 Middle line and surface alignment</td>
<td>39</td>
</tr>
<tr>
<td>7.3.3 Tolerances for vessels</td>
<td>40</td>
</tr>
<tr>
<td>7.4 Weld details</td>
<td>41</td>
</tr>
<tr>
<td>7.4.1 Recommended weld details</td>
<td>41</td>
</tr>
<tr>
<td>7.4.2 Vessels made in more courses</td>
<td>42</td>
</tr>
<tr>
<td>7.5 Joggle joints</td>
<td>42</td>
</tr>
<tr>
<td>7.5.1 General</td>
<td>42</td>
</tr>
</tbody>
</table>
Foreword

This document (EN 13831:2007) has been prepared by Technical Committee CEN/TC 54 “Unfired pressure vessels”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2008, and conflicting national standards shall be withdrawn at the latest by February 2008.

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

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

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

Closed expansion vessels with built in diaphragm made their commercial début in the early 1950s. They were employed in heating systems, or for fresh water supply systems.

When used in heating systems they take up the increase of the water volume due to the heating up. The gas pressure (on the other side of the diaphragm) pushes the water back into the system when due to cooling down the water volume in the heating system is decreasing. Expansions vessels with built in diaphragm are an undisputed standard in European heating engineering. When used in fresh water circuits, vessels with built in diaphragm serve to accommodate the extra volume caused by water heaters warming up, thus saving valuable drinking water from flowing down the drain. The other main application is to store water under pressure in connection with booster systems allowing an energy efficient pump operation.

Though the development of the closed expansion vessel with built in diaphragm constituted a real revolution in the domains of heating and drinking water, industry in general took only limited note of it. Nevertheless this has not prevented the manufacturers from refining the product and the manufacturing technique over the last 40 years, often charting entirely new paths. As a consequence, the production of closed expansion vessels can differ considerably from conventional pressure vessel production. This is especially true in respect to the highly developed deep drawing technology.
1 Scope

This European Standard specifies requirements for the design, manufacture and testing of closed expansion vessels with built in diaphragm, which will hereinafter be called "vessels", and

a) whose diaphragm serves to separate water on the one hand and air / nitrogen on the other hand in heating/cooling systems or fresh water systems;

b) which are manufactured singly or in series;

c) which may consist partly or entirely of (cold) deep-drawn parts;

d) whose parts may be joined by welding, clenching or flanges;

e) whose size is not limited;

f) whose maximum allowable pressure is greater than 0,5 bar, yet not exceeding 30 bar;

g) whose upper wall thickness is limited to 12 mm for austenitic steels and 15 mm for ferritic steels;

h) whose minimum operating temperature is not below –10 °C and whose maximum operating temperature is not above 70 °C.

NOTE The maximum operating temperature of 70 °C is determined by the characteristics of the diaphragm materials. It may be higher, if suitability of diaphragm material is proven.

Whatever the temperature in the heating system, for the vessel operation the decisive factor is the maximum operating temperature of the diaphragm. It is the system designer's responsibility to prescribe measures to protect the diaphragm from unsuitable temperatures (e.g. connection to the coldest part of the system in a heating system, to the warmest in a refrigeration circuit; thermostatic monitoring of connection to vessel or intermediate vessel).

For cases where operating temperatures above 70 °C cannot be avoided the suitability of the diaphragm material is to be proven (see Clause 8).

When reference is made in this European Standard to EN 13445-1, EN 13445-2, EN 13445-3, EN 13445-4 and EN 13445-5 respectively, all relevant provisions in the concerned clauses of these standards need to apply.

2 Normative references

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


EN 473:2000, Non destructive testing — Qualification and certification of NDT personnel — General principles


EN 764-3:2002, Pressure equipment — Part 3: Definition of parties involved

EN 895:1995, Destructive tests on welds in metallic materials — Transverse tensile test

EN 910:1996, Destructive test on welds in metallic materials — Bend tests
EN 1418:1997, Non-destructive examination of welds — Radiographic examination of welded joints
EN 10240:2004, Metallic products — Types of inspection documents
EN 10269:1999, Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties
EN 13445-1:2002, Unfired pressure vessels — Part 1: General
EN 13445-2:2002, Unfired pressure vessels — Part 2: Materials
EN 13445-3:2002, Unfired pressure vessels — Part 3: Design
EN 13445-4:2002, Unfired pressure vessels — Part 4: Fabrication
EN 13445-5:2002, Unfired pressure vessels — Part 5: Inspection and testing

3 Terms and conditions

For the purposes of this document, the terms and definitions given in EN 764-1:2004, EN 764-2:2002, EN 764-3:2002 and the following apply.

3.1 automatic welding
welding in which all the parameters are automatically controlled, some of these parameters may be adjusted to a limited amount (manually or automatically by mechanical or electronic devices) during welding to maintain the specified welding conditions

3.2 clench joints
separate metal ring holding together two vessel parts or a rolled joint holding together two vessel parts in a permanent way. Its design is always done according to the experimental design method

3.3 expansion vessel
vessel to take up the volume variations of a liquid due to changes of temperature. The expansion vessel is called "closed", if the liquid contained is not in contact with any gaseous or liquid medium.
3.4 deep drawing
forming of vessel parts from a flat state into a three dimensional state by means of a press and tools whereby
no material is taken off or added

3.5 diaphragm
flexible and/or elastic wall which is fastened into the vessel inside in a gas tight way and separates the
vessel into a water and a gas space

3.6 experimental test
any kind of test used to substitute for the calculation of a vessel part or the whole vessel, within the framework
of the experimental design method

3.7 inspection document
document according to EN 10204:2004

3.8 family of welded joints
welded joints covered by a specific welding procedure approval document

3.9 vessel family
vessels belong to one vessel family if they have similar geometrical proportions, same design and fall within
the validity of one weld procedure approval

3.10 freshwater
water coming from a supply system (mains, well etc.), untreated apart from possible hygienic measures, with
natural content of oxygen
4 Symbols and units


Other symbols used in specific clauses of this European Standard are tabulated there.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Area</td>
<td>mm²</td>
</tr>
<tr>
<td>A</td>
<td>elongation after fracture</td>
<td>%</td>
</tr>
<tr>
<td>d, D</td>
<td>Diameter</td>
<td>mm</td>
</tr>
<tr>
<td>e</td>
<td>Thickness</td>
<td>mm</td>
</tr>
<tr>
<td>f</td>
<td>nominal design stress for design conditions</td>
<td>MPa or N/mm²</td>
</tr>
<tr>
<td>f_{test}</td>
<td>nominal design stress for testing conditions</td>
<td>MPa or N/mm²</td>
</tr>
<tr>
<td>l</td>
<td>Length</td>
<td>mm</td>
</tr>
<tr>
<td>p</td>
<td>design pressure</td>
<td>bar, MPa or N/mm² ¹)</td>
</tr>
<tr>
<td>PS</td>
<td>maximum allowable pressure</td>
<td>bar, MPa or N/mm² ¹)</td>
</tr>
<tr>
<td>PT</td>
<td>test pressure</td>
<td>bar, MPa or N/mm² ¹)</td>
</tr>
<tr>
<td>r, R</td>
<td>Radius</td>
<td>mm</td>
</tr>
<tr>
<td>R_y</td>
<td>yield strength</td>
<td>MPa or N/mm²</td>
</tr>
<tr>
<td>R_{uH}</td>
<td>upper yield strength</td>
<td>MPa or N/mm²</td>
</tr>
<tr>
<td>R_m</td>
<td>tensile strength</td>
<td>MPa or N/mm²</td>
</tr>
<tr>
<td>R_{m/t}</td>
<td>tensile strength at temperature t °C</td>
<td>MPa or N/mm²</td>
</tr>
<tr>
<td>R_{p0.2/t}</td>
<td>0.2 % proof strength at temperature t °C</td>
<td>MPa or N/mm²</td>
</tr>
<tr>
<td>R_{p1.0/t}</td>
<td>1.0 % proof strength at temperature t °C</td>
<td>MPa or N/mm²</td>
</tr>
<tr>
<td>TS</td>
<td>temperature</td>
<td>°C</td>
</tr>
<tr>
<td>t_c</td>
<td>calculation temperature</td>
<td>°C</td>
</tr>
<tr>
<td>t_t</td>
<td>test temperature</td>
<td>°C</td>
</tr>
<tr>
<td>V</td>
<td>volume, capacity</td>
<td>m³, L, (l)</td>
</tr>
<tr>
<td>z</td>
<td>weld joint coefficient</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

The unit bar is needed to meet the general terminology, and thus to be used on nameplates, certificates, drawings, pressure gauges and instrumentation.

¹) MPA or N/mm² for calculation purpose only.
5 Materials

5.1 General

The grouping according to Table 5.1-1 is based on materials corresponding to steel groups 1; 1.1; 8.1 as defined in EN 13445-2:2002.

Table 1 — Definitions of steel groups (CEN ISO/TR 15608:2005)

<table>
<thead>
<tr>
<th>Group/Subgroup</th>
<th>Type of steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steels with a minimum yield strength ( R_{eH} \leq 460 \text{ N/mm}^2 ) and with analysis in % (ladle analysis):</td>
</tr>
<tr>
<td></td>
<td>C \leq 0,25</td>
</tr>
<tr>
<td></td>
<td>Si \leq 0,60</td>
</tr>
<tr>
<td></td>
<td>Mn \leq 1,70</td>
</tr>
<tr>
<td></td>
<td>Mo \leq 0,70</td>
</tr>
<tr>
<td></td>
<td>S \leq 0,045</td>
</tr>
<tr>
<td></td>
<td>P \leq 0,045</td>
</tr>
<tr>
<td>1.1</td>
<td>Steels with a minimum yield strength ( R_{eH} \leq 275 \text{ N/mm}^2 ) and composition as indicated under 1</td>
</tr>
<tr>
<td>8.1</td>
<td>Austenitic stainless steels with Cr \leq 19 % (content used in steel designation)</td>
</tr>
</tbody>
</table>

\( a \) In accordance with the specification of the steel product standards, \( R_{eH} \) may be replaced by \( R_{p0,2} \) or \( R_{t0,5} \).

\( b \) A higher value is accepted provided that \( Cr + Mo + Ni + Cu + V \leq 0,75 \% \).

For a complete overview of steel grades falling into the above mentioned groups reference is made to EN 13445-2:2002.

5.2 Materials proven by experience and current use

The following materials do not fulfil all the requirements of groups 1, 1.1 and 8.1, but may be used for this type of product under the condition that there is sufficient ductility of the material after forming as it will be used is proven:

- EN 10025-2\(^2\)  grades S 235 J2, S 235 JR;
- EN 10130\(^3\)    grades Dc01, Dc03, Dc04;
- EN 10111\(^3\)    grades DD11, DD12, DD13, DD14.

\(^2\) See 6.3.2.5.

\(^3\) Restricted use, see 6.2.
5.3 Fasteners

Fasteners (bolts, nuts, studs) shall not be made from free cutting steel. Used steels shall have an elongation after fracture, $\varepsilon$, of at least 14%.

Bolts and screws in accordance with EN ISO 898-1:1999 property classes 5.6 or 8.8 and nuts to ISO 898-2:1998 property classes 5 or 8 but with an elongation of at least 12%, shall be considered suitable.

EN 10269:1999 shall be taken into account.

5.4 Non-pressurised parts

For non-pressure parts welded to pressure vessels, materials shall be used which are supplied to material specifications covering at least the requirements for the chemical composition and the tensile properties. These materials shall not limit the operating conditions of the material to which they are attached.

6 Design and calculation

6.1 Design

6.1.1 Requirements pertaining to the diaphragm

Sharp edges and corners (grooves, welding beads etc.) are not permitted in those areas of the inside surface which will come into contact with the diaphragm.

Parts projecting into the vessel in such a way, that damage of the diaphragm can occur are not permitted.

Local concavities on the inner surface are only permitted if the maximum possible linear stretching of the diaphragm being pressed into the concavity is not above 10% of the elongation at rupture of the diaphragm material.

Openings in the vessel wall shall be designed in such a way that the diaphragm cannot be damaged through impingement.

The gaps of joggled welds shall nowhere be bigger than twice the diaphragm wall-thickness.

The dimensions of the vessel and the diaphragm shall match so as to ensure that irrespective of charge pressure the diaphragm cannot be stretched to the point where it is damaged.

6.1.2 Requirements pertaining to fresh water application

Metal parts in contact with the water during normal operation of the vessel shall be of stainless steel, corrosion resistant or adequately protected against corrosion.

6.1.3 Outside finish

The vessel and its outside parts shall be so finished as to avoid injury (e.g. from burs and sharp edges). Vessels made of carbon steel shall be protected against ambient corrosion.

6.1.4 Inspection openings

6.1.4.1 Vessels with fixed diaphragms do not require openings.

6.1.4.2 Vessels with a removable diaphragm shall have an opening of sufficient size to exchange the diaphragm. This opening serves also for inspection purposes.
6.1.4.3 Vessels with removable diaphragm, with additional compartments, shall have an inspection opening of ≥ 30 mm inside diameter in the additional compartment such that the vessel can be inspected.

6.1.5 Connections

6.1.5.1 Minimum size of water connections shall be according to Table 2.

Table 2 — Minimum size of water connections

<table>
<thead>
<tr>
<th>Vessel volume [L]</th>
<th>Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>V ≤ 12</td>
<td>DN 12 (0.375&quot;)</td>
</tr>
<tr>
<td>12 &lt; V ≤ 25</td>
<td>DN 15 (0.5&quot;)</td>
</tr>
<tr>
<td>25 &lt; V ≤ 600</td>
<td>DN 20 (0.75&quot;)</td>
</tr>
<tr>
<td>600 &lt; V ≤ 1 000</td>
<td>DN 25 (1&quot;)</td>
</tr>
<tr>
<td>1 000 &lt; V ≤ 2 000</td>
<td>DN 32 (1.25&quot;)</td>
</tr>
<tr>
<td>2 000 &lt; V</td>
<td>DN 40 (1.5&quot;)</td>
</tr>
</tbody>
</table>

NOTE For vessels used in freshwater applications larger connections could be required, depending on the flow rate.

6.1.5.2 If the water connection is covered by any kind of sieve, its total free section shall be a least equal to the free section of the connection pipe as specified in 6.1.5.1.

6.1.6 Clenched joints

In the case of clenched joints the experimental design method shall be used to determine minimum wall thickness. There is therefore no calculation method for them in the European Standard.

Within the framework of a type approval, in deviation from 6.2.2, at least 6 vessels have to be tested according to 6.2.3 or 6.2.4.

In the case of different vessel sizes within a family, a minimum of 2 vessels per vessel size have to be tested according to 6.2.3 or 6.2.4 if \( PS \times V \leq 1000 \text{ bar} \times \text{L} \).

In the case of different vessel sizes within a family, a minimum of 1 vessel per vessel size has to be tested according to 6.2.3 or 6.2.4 if \( 1000 \text{ bar} \times \text{L} < PS \times V < 6000 \text{ bar} \times \text{L} \).

Circumferential measurements have to be carried out in the cylindrical part of the vessel above and below the clenched joint. The maximum allowable permanent deformation shall not be higher than 1 % (see 6.2.3 and 6.2.4).

NOTE Owing to the wide variety of versions and designs of this type of joint it is impossible to indicate further dimensions or physical properties.

6.1.7 Volume tolerance of vessels

The actual volume of the vessel measured without the diaphragm, shall be a minimum of 95 % of the (nominal) volume declared by the manufacturer.

6.1.8 Fatigue

Expansion vessels as covered by this European Standard are operated in such a way that no relevant fatigue load occurs.
6.1.9 Loadings

Expansion vessels are normally installed inside buildings and external loadings are not significant. For vessels where weight or static head of the fluid have to be taken into account, reference should be made to EN 13445-3:2002. The same applies where the specification for the vessel stipulates conditions which lead to special loadings (e.g. earthquake loadings).

6.2 Experimental design method

6.2.1 General

The design for adequate strength may be determined by the use of the experimental design method for vessels with a $PS \times V < 6,000$ bar $L$.

EN 10130, grades Dc01, Dc03 and Dc04 and EN 10111, grades DD11, DD12, DD13 and DD14 may only be used in accordance with 5.2 when the design is verified according to the experimental design method in this subclause. Since these are intended for deep drawing the mechanical values in their respective standards do not lend themselves to the calculation method of 6.3.

The minimum wall thickness shall not be less than 0.8 mm at any point.

6.2.2 Preparations

The experimental test is performed on that vessel size within a family which will give the least favourable results under pressure (normally the one with the biggest diameter).

Vessels to be submitted to the test have to be identical to normal production with the exception that they shall not contain a complete diaphragm.

If for production reasons the complete diaphragm has to be built into the vessel, holes shall be made into the diaphragm to ensure that there is water on both sides of the diaphragm, so that leaks will then be visible irrespective of their position relative to the diaphragm.

If the vessel selected fails, two more vessels of the same size shall be submitted to the same test. The design is only acceptable if both vessels then pass the test. The water used for testing shall be at room temperature. The permanent deformation (elongation of shell) shall be measured along the shortest circumference of the vessel.

A report of the test shall be drawn up giving all necessary information so as to validate the test results including material certificates for the main parts of the vessel.

6.2.3 Vessels with $PS \times V \leq 1,000$ bar $L$

The vessels to be tested shall be completely filled with water, then pressurised up to $2 \times PS$ (–0 % + 5 %) and held at this pressure for 5 min. No leaks shall occur during this time. The permanent deformation shall not be higher than 1 %.

6.2.4 Vessels with $1,000$ bar $L < PS \times V < 6,000$ bar $L$

The vessels to be tested shall be completely filled with water, then pressurised up to $3 \times PS$ (–0 % + 5 %) and held at this pressure for 5 min. No leaks shall occur during this time. The permanent deformation shall not be higher than 1 %.

6.2.5 Vessel parts and components

When the experimental design method is used for vessel parts and components that are pressurized, they shall be subjected to an experimental test of $3 \times PS$ (–0 % + 5 %) and held at this pressure for 5 min. No leaks shall occur during this time.
6.3 Calculation method

6.3.1 General

This clause covers the calculation of those parts and components which are normally used for expansion vessels.

For cases not covered by this clause, reference should be made to EN 13445-3:2002.

6.3.2 Symbols

6.3.2.1 General

For symbols in general, reference should be made to Clause 4. Symbols used only in specific clauses are listed at the beginning of the respective clause.

6.3.2.2 Design pressure

The design pressure \( p \) is determined by the vessel manufacturer and cannot be lower than \( P_S \).

6.3.2.3 Calculation temperature

The temperature \( t_c \) to be used for the calculation of the vessel shall be determined by the vessel manufacturer within the limits – 10 °C / + 110 °C. It shall not be lower than the design temperature.

NOTE The upper limit of 110 °C is purely for calculation purposes. It is not relevant for the vessel operation since apart from very special rubber materials the diaphragm in the vessel is not to be operated at temperatures above 70 °C.

6.3.2.4 Nominal design stresses

Steels other than austenitic

\[
f = \text{MIN} \left( \frac{R_{p0,2t}}{1,5}, \frac{R_{m20}}{2,4} \right)
\]

When \( R_{p0,2t} \) is not specified in the material standard \( f = \frac{R_{m20}}{2,8} \)

Austenitic steels with \( A \geq 30 \% \)

\[
f = \frac{R_{p1,0t}}{1,5}
\]

Austenitic steels with \( A \geq 35 \% \)

\[
f = \frac{R_{p1,0t}}{1,5} \text{ or MIN} \left( \frac{R_{p1,0t}}{1,2}, \frac{R_{min}}{3} \right)
\]

6.3.2.5 Weld joint coefficient

The weld joint coefficient shall be chosen by the manufacturer:

\( z = 1 \) NDT on every vessel;

\( z = 0,85 \) spot NDT;
\[ z = 0.7 \quad \text{only visual examination.} \]

6.3.2.6 Allowances

6.3.2.6.1 Allowance to compensate for plate thickness and manufacturing tolerances

For ferritic steels, the thickness tolerance to be used in the calculation is the negative tolerance in the relevant dimensional standard for the finished component.

Where the manufacturing process entails reduction in thickness the minimum required wall thickness shall be stated on the drawing.

6.3.2.6.2 Corrosion allowance

No allowance for corrosion is made in this European Standard.

NOTE Water in normal heating systems is not considered corrosive. Vessels in drinking water systems need to have metal parts protected against corrosion (see 6.1.2).

6.3.3 Cylindrical and spherical shells under internal pressure

6.3.3.1 Specific symbols

- \( D_e \) outside diameter of the shell
- \( e \) required shell thickness

6.3.3.2 Cylindrical shells

The required wall thickness \( e \) is given by

\[
e = \frac{p \cdot D_e}{2 f \cdot z + p}
\]

(4)

6.3.3.3 Spherical shells

The required wall thickness \( e \) is given by

\[
e = \frac{p \cdot D_e}{4 f \cdot z + p}
\]

(5)

6.3.4 Dished ends under internal pressure

6.3.4.1 General

These design rules apply to dished ends of the torispherical, ellipsoidal and hemispherical type, not welded (i.e. made of one piece of sheet metal).

6.3.4.2 Specific symbols

- \( \beta \) function of \( e/R \) and \( r/D_i \) for torispherical ends given by Figure 2
- \( e \) required thickness of the knuckle
- \( D_e \) outside diameter of end
- \( D_i \) inside diameter of end
6.3.4.3 Hemispherical ends

The required thickness of a hemispherical end is given by Equation (5).

6.3.4.4 Torispherical ends

A torispherical end is made up of a spherical cap, a toroidal knuckle and a cylindrical shell, the three components having tangents where they meet.

The following rules are limited to ends for which:

a) \( r \leq 0.2 \, D_i \)

b) \( r \geq 0.06 \, D_i \)

c) \( r \geq 2 \, e \)

d) \( e \leq 0.08 \, D_e \)

e) \( e > 0.005 \, D_i \) (if this condition is not fulfilled, \( e \) has to be checked additionally for plastic buckling. See EN 13445–3)

f) \( R \leq D_e \)
The required thickness $e$ is the greater of the following values

$$e = \frac{\beta \cdot p \cdot (0.75 \cdot R + 0.2 \cdot D_i)}{f}$$  \hspace{1cm} (6)

$$e = \frac{p \cdot R}{2f \cdot z - 0.5p}$$  \hspace{1cm} (7)

---

**Figure 2 — Torispherical end design (factor $\beta$)**

---

### 6.3.4.5 Ellipsoidal ends

An ellipsoidal end is made on a truly ellipsoidal former.

These rules apply only to ends for which $1.7 < K < 2.2$.

Ellipsoidal ends shall be designed as nominally equivalent torispherical ends with:

$$\frac{r}{D_i} = 0.5 / K - 0.08 \text{ and } \frac{R}{D_i} = 0.44 \cdot K + 0.02$$  \hspace{1cm} (8, 9)

---

### 6.3.4.6 Nozzles intruding into the knuckle region

For calculation of nozzles intruding into the knuckle region see EN 13445-3.
6.3.5 Openings in cylindrical shells, spherical shells and dished ends

6.3.5.1 General

The design method in this clause is applicable to cylindrical shells, spherical shells and dished ends having circular openings. It does not apply for adjacent openings, elliptical or obround openings, oblique nozzles or openings close to discontinuities (e.g. weld seams). For this, reference should be made to EN 13445-3:2002.

Cylindrical shells, spherical shells and dished ends having an opening shall be adequately reinforced. The reinforcement area of a shell having an opening cannot be calculated directly but shall be assumed in the first instance. This assumption has to be verified. If the verification’s result is not sufficient, the calculation shall be repeated using a modified assumption. Nozzles, reinforcing rings and compensating plates can only be considered for reinforcement of openings if they are welded to the shell with adequate welds. They can be used in combination with one another or singly. A reinforcement shall be sufficient in all planes through the axis of the opening or nozzle.

This subclause does not apply for reinforcing by increased wall thickness of a nozzle or / and the shell.

6.3.5.2 Symbols and Units

- \(a\) distance, taken along the average wall surface on the clause where the reinforcement of an opening has to be calculated between the openings centre and the external edge of a nozzle or of a ring; if no nozzle or ring is present, \(a\) is the distance between the centre and the internal edge of the opening
- \(A_f\) stress loaded cross sectional area effective as compensation
- \(A_{fb}\) stress loaded cross sectional area of nozzle
- \(A_{fp}\) stress loaded cross sectional area of compensating plate
- \(A_{fr}\) stress loaded cross sectional area of reinforcing ring
- \(A_{fs}\) stress loaded cross sectional area of shell wall (main body)
- \(A_p\) pressure loaded area
- \(A_{ps}\) pressure loaded area of shell (main body)
- \(A_{pb}\) pressure loaded area of nozzle
- \(A_{pr}\) pressure loaded area of reinforcing ring
- \(d\) diameter (or maximum width) of opening, or inside diameter of a nozzle
- \(d_e\) outside diameter
- \(d_{eb}\) outside diameter of nozzle
- \(d_{ep}\) outside diameter of compensating plate
- \(d_{er}\) outside diameter of reinforcing ring
- \(d_i\) inside diameter
- \(d_{ib}\) inside diameter of nozzle (\(d\) of set-in nozzle)
- \(d_{ip}\) inside diameter of compensating plate
- \(d_{ir}\) inside diameter of reinforcing ring
- \(D_e\) external diameter of cylindrical or spherical shell at the centre of an opening
- \(D_i\) internal diameter of cylindrical or spherical shell at the centre of an opening
- \(e_b\) required thickness of nozzle (or mean thickness within the length \(l_{bo}\) or \(l_{bo}\))
- \(e_{a, b}\) analysis thickness of nozzle useful for reinforcement
- \(e_{p}\) required thickness of compensating plate
6.3.5.3 Limitations

Shell reinforced openings without a nozzle and/or reinforcing plate as well as those reinforced exclusively by a reinforcing plate the ratio \( \frac{d}{l} \times \frac{2}{r_a} \) shall not exceed 0.5.

For openings in cylindrical shells reinforced by nozzles it shall not exceed 1.

On dished ends openings, nozzles, compensating plates and reinforcing rings shall be completely located inside the central area limited by a radius equal to 0.4 \( D_e \).
For spherical shells and dished ends the ratio $d / D_e$ shall not exceed the value of 0.6.

Openings on cylindrical shells close to discontinuities (Figure 3) shall satisfy the following condition:

$$w \geq w_{\text{min}} = \text{MAX} \left( 0.2 \cdot l_{so} \cdot 3e_{a,s} \right)$$

(10)

![Figure 3 — Discontinuities in cylindrical shells](image)

If an opening diameter (or maximum width) $d$ satisfying the following condition:

$$d \leq 0.15 \sqrt{(2 \cdot r_{is} + e_{a,s}) \cdot e_{a,s}}$$

(11)

it is considered a “small opening” and needs no reinforcement.

6.3.5.4 Cylindrical shells, spherical shells and dished ends with isolated openings

6.3.5.4.1 Isolated openings

Adjacent openings or nozzles may be regarded as isolated openings if the minimum centre-to-centre distance $L_b$ between the openings or nozzles taken along the average shell surface satisfies the following condition:

$$L_b \geq a_1 + a_2 + l_{so1} + l_{so2}$$

(12)

where

$l_{so1}$ and $l_{so2}$ are calculated for each opening, and where $a_1$ and $a_2$ are the straight or arched distances (taken on the mean radius) along $L_b$ from the centre until the external diameter of each opening as shown in Figure 4:

$$l_{so} = \sqrt{(2 \cdot r_{is} + e_{a,s}) \cdot e_{a,s}}$$

(13)

where

— $r_{is}$ is the inside radius of curvature of the shell at the centre of each opening, i.e.:

for cylindrical or spherical shells $r_{is} = (D / 2) - e_s$

(14)

for hemispherical or torispherical ends $r_{is} = R$

(15)

for elliptical ends $r_{is} = 0.44 \cdot D_i^2 / (2h) + 0.02 \cdot D_i$

(16)
— \( e_{as} \) is the analysis wall thickness of the shell, or the mean analysis thickness on the length \( l_{ao} \) without taking into account any compensation plate thickness.

a) In cylindrical shells  

b) In spherical shells and dished ends

Figure 4 — Openings

6.3.5.4.2 General formula for reinforcement of openings

For isolated openings the following general condition shall be satisfied (Figure 5):

\[
A_f \cdot (f - 0.5p) + A_{fb} \cdot (f_{op} - 0.5p) + A_{ob} \cdot (f_{ob} - 0.5p) \geq p \cdot (A_{ps} + A_{pb}) \tag{17}
\]

Terms related to nozzle may be substituted by terms related to reinforcing ring; moreover

\[
f_{ob} = \text{MIN} (f; f_o) \tag{18}
\]

\[
f_{op} = \text{MIN} (f; f_p) \tag{19}
\]
a) In cylindrical shells

b) In spherical shells and dished ends

Figure 5 — Reinforcement of isolated opening

For openings reinforced by nozzles, plates or rings the following formulae apply (where $l'_s = \text{MIN} \left( l'_{a,s}, l_s \right)$):

— for cylindrical shells, calculation on the longitudinal cross section

$$Ap_s = r_{ls} \cdot (l'_s + a)$$  \hfill (20)

where $a = 0.5 \cdot d_{eb}$  \hfill (21)

— for dished ends, spherical shells, cylindrical shells when the calculation is needed in the transverse cross section:

$$Ap_s = \frac{0.5r_{ls} \cdot (l'_s + a)}{(0.5e_{a,s} + r_{ls})}$$  \hfill (22)

$$a = r_{ma} \cdot \arcsin \left( \frac{d_{eb}}{2 \cdot r_{ma}} \right)$$  \hfill (23)

$arcsin$ in radiant

where

$$r_{ma} = r_{ls} + 0.5e_{a,s}$$  \hfill (24)

Moreover:

— for set-in nozzles, reinforcing plates or rings:

$$Af_s = l'_s \cdot e_{a,s}$$  \hfill (25)

— for set-on nozzles:

$$Af_s = e_{a,s} \cdot (e_{a,b} + l'_s)$$  \hfill (26)
6.3.5.4.3 Reinforcement by compensating plates

The width of a compensating plate \( l_p \) to be considered as contributing to reinforcement is (see Equation (6.3–13) and Figure 6.3–6):

\[
l_p' = \text{MIN}\ (l_{so}, l_p)
\]

(27)

The value of \( e_p \) used for the calculation of \( Af_p \) shall not exceed the thickness \( e_{a,s} \) of the shell

\[
e_p = \text{MIN}\ (e_{a,p}, e_{a,s})
\]

(28)

Furthermore condition 6.3–17 shall be satisfied, where \( Af_p = e_{a,p} \cdot l_p' \).

![Diagram showing reinforcement by compensating plates](image)

(a) In cylindrical shells  
(b) In spherical shells and dished ends

Figure 6 — Reinforcement by compensating plates

6.3.5.4.4 Reinforcement by reinforcing rings

The width \( l_r \) of the ring considered as contributing to the reinforcement shall be (see Equation (13) and Figure 6.3–7):

\[
l_r' = \text{MIN}\ (l_{so}, l_r)
\]

(30)

The value of \( e_r \) used for the calculation \( Af_r \) shall be:

\[
e_r = \text{MIN}\ (e_{a,r}, \text{MAX}(3e_{a,s}, 3l_r))
\]

(31)

Furthermore equation (6.3–17) shall be satisfied, where

\[
Af_r = e_r \cdot l_r'
\]

(32)

\[
Ap_r = 0.5d_r e_r
\]

(33)

\[
Af_s = e_{a,s} \cdot l_s'
\]

(34)
6.3.5.4.5 Reinforcement by nozzles (branches)

The maximum nozzle length contributing to the reinforcement shall not be greater than

\[ l_{bo} \]

with:

\[ l_{bo} = \sqrt{(d_{eb} + e_{a,b}) \cdot e_{a,b}} \] (35)

The maximum value to be used in the calculation for the inside protruding part of the nozzle in the case of set-through nozzles shall be:

\[ l'_{bo} = \text{MIN} (l_{bo}; 0.5 \cdot l_{bo}) \] (36)

The condition of equation 17 shall be satisfied, where (see Figure 8):

— for set-in nozzle:

\[ A_{f_b} = e_{a,b} \cdot (b'_s + h'_b + e'_s) \] (37)

— for set-on nozzle:

\[ A_{f_b} = e_{a,b} \cdot b'_s \] (38)

with:

\[ l'_{bo} = \text{MIN} (l_{bo}; l_b) \] (39)

\[ e'_s \text{ = length of penetration (full or partial) of set-in nozzle into shell wall (} \leq e_{a,s} \) \]

\[ A_{pb} = 0.5 \cdot d_{ib} \cdot (h'_s + e_{a,s}) \] (40)
6.3.6 Bolted circular flat ends under internal pressure

6.3.6.1 General

These design rules apply to unstayed circular flat ends under internal pressure connected to the vessel by bolting, and take into account reinforcement of openings.

For all other kinds of flat ends reference should be made to EN 13445-3:2002.

6.3.6.2 Symbols

- $A$ : nozzle reinforcement area \( \text{mm}^2 \)
- $b$ : effective gasket or joint width,
  \[ b = b_o \text{ when } b_o < 6.3 \text{ mm} \]
  \[ b = 2.25 \sqrt{b_o} \text{ when } b_o > 6.3 \text{ mm}, (b_o \text{ is the basic gasket or joint seating width } = w / 2 \text{ with the exception of the ring-joint for which } b_o = w / 8) \] \( \text{mm} \)
- $d$ : diameter of an opening \( \text{mm} \)
- $d_i$ : nozzle inside diameter \( \text{mm} \)
- $d_e$ : nozzle outside diameter \( \text{mm} \)
- $D_i$ : inside diameter of the cylindrical shell / pipe / opening to which the end is bolted \( \text{mm} \)
- $C$ : diameter of the bolt circle \( \text{mm} \)
- $G$ : mean diameter of gasket \( \text{mm} \)
- $e$ : minimum required wall thickness of the end \( \text{mm} \)
6.3.6.3 Unstayed flat circular bolted ends without openings

6.3.6.3.1 General

These design rules relate to the following ends:

— gaskets entirely within the bolt circle (narrow-face);
— gaskets on both sides of the bolt circle (full-face).

The ends may or may not be of uniform thickness. However the minimum required wall thickness has to be extended to the entire surface located inside the gasket.
6.3.6.3.2 Circular ends with gasket entirely within the bolt circle

![Diagram of circular ends with gaskets]

**Figure 9 — Bolted circular flat ends with gasket entirely within the bolt circle**

The minimum required wall thickness $e$ for the end is the greater value calculated from Equations (41) and (42) respectively.

---

For the gasket seating condition:

$$e_A = \sqrt[3]{\frac{3}{\pi} (C - G) \cdot W_{amb}}$$  (41)

For each pressure condition:

$$e_p = \sqrt{0.31 \cdot G^2 + 3 \left( \frac{G}{4} + 2 \cdot b \cdot m \right) \cdot (C - G) \cdot \frac{P}{f}}$$  (42)

$W_{amb}$ is given by the following equation:

$$W_{amb} = \pi \cdot b \cdot G \cdot y$$  (43)

The minimum required wall thickness $e_1$ for the peripheral area end is given by Equation (41) or the following for each pressure condition whichever is greater.
\[ e_{pl} = \sqrt{3 \left( \frac{G}{4} + 2 \cdot b \cdot m \right) \cdot (C - G) \cdot \frac{P}{f}} \] \hspace{1cm} (44)

6.3.6.3.3 Circular ends with gasket on both sides of the bolt circle (full faced gasket flange)

![Diagram](image)

Figure 10 — Bolted circular flat end with a gasket on both sides of the bolts

The minimum required wall thickness for the end is given by the following equation:

\[ e = 0.41 \cdot C \cdot \sqrt{\frac{P}{f}} \] \hspace{1cm} (45)

The minimum required wall thickness for the peripheral area of the end is given by:

\[ e_1 = 0.8 \cdot e \] \hspace{1cm} (46)

The reduced thickness of the flanged extension shall be limited to a crown area whose internal circumference is not smaller than 0.7 \(C\).
### Table 3 — Gasket factors \((m)\) and minimum design seating pressures \((\nu)\)

<table>
<thead>
<tr>
<th>Gasket material</th>
<th>Gasket factor (m)</th>
<th>Minimum design seating stress (\nu) (N/mm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber without fabric or high percentage of asbestos (^a) fibre:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>below (75^\circ) BS and IRH</td>
<td>0,50</td>
<td>0,0</td>
</tr>
<tr>
<td>(75^\circ) BS and IRH or higher</td>
<td>1,00</td>
<td>1,4</td>
</tr>
<tr>
<td>Asbestos (^a) with a suitable binder for</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the operating conditions</td>
<td>3,2 mm thick</td>
<td>2,00</td>
</tr>
<tr>
<td></td>
<td>1,6 mm thick</td>
<td>2,75</td>
</tr>
<tr>
<td></td>
<td>0,8 mm thick</td>
<td>3,50</td>
</tr>
<tr>
<td>Rubber with cotton fabric insertion</td>
<td>1,25</td>
<td>2,8</td>
</tr>
<tr>
<td>Rubber with asbestos (^a) fabric</td>
<td>3-play</td>
<td>2,25</td>
</tr>
<tr>
<td>insertion, with or without wire</td>
<td>2-play</td>
<td>2,5</td>
</tr>
<tr>
<td>reinforcement</td>
<td>1-play</td>
<td>2,75</td>
</tr>
<tr>
<td>Vegetable fibre</td>
<td></td>
<td>1,75</td>
</tr>
<tr>
<td>Rubber O-rings:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>below (75^\circ) BS</td>
<td>0 to 0,25</td>
<td>0,7</td>
</tr>
<tr>
<td>(75^\circ) BS and 85(^\circ) BS and IRH</td>
<td>1,4</td>
<td></td>
</tr>
<tr>
<td>Rubber square section rings:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>below (75^\circ) BS and IRH</td>
<td>0 to 0,25</td>
<td>1,0</td>
</tr>
<tr>
<td>(75^\circ) BS and 85(^\circ) BS and IRH</td>
<td>2,8</td>
<td></td>
</tr>
<tr>
<td>For other gasket material reference should made to EN 13445-3.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) In many countries materials containing asbestos are prohibited. New non-asbestos bonded fibre sheet gaskets are not necessarily direct substitutes for asbestos based materials. Use within the manufacturer’s recommendations.

\(^b\) \(75^\circ\) corresponds to 85 Shore A, 85\(^\circ\) to 95\(^\circ\) Shore A.

### 6.3.6.4 Reinforcement of openings in unstayed flat circular ends

These design rules apply to reinforcement of single or multiple openings in unstayed circular flat ends, provided their diameter is smaller than 50 % of the gasket mean diameter \(G / C\).

Blind screwed holes of stud-bolts for connection to standard pipe flanges do not need reinforcement, provided they are located around an opening having a diameter not greater than the maximum bore diameter of the standard flange which should be bolted to that opening, and provided the thickness at the bottom of the bore is at least 50 % of the stud-bolt diameter.

For bolted ends the wall thickness shall be:

\[
e = Y_2 e_0
\]  \(\text{(47)}\)

where

\[
Y_2 = \sqrt{\frac{k}{k - d}}
\]  \(\text{(48)}\)

where \(k\) for a single opening is equal to \(D_i\)

when the opening has a nozzle, \(d\) is given by:

in case of set on nozzles:
\[ d = d_i - \frac{2 \cdot A'}{e_b} \]  \hspace{1cm} (49)

in case of set-in nozzles:

\[ d = d_e - \frac{2 \cdot A'}{e_b} \]  \hspace{1cm} (50)

where

\[ A' = \text{MIN}\left( A : A \frac{f_b}{f} \right) \]  \hspace{1cm} (Figure 6.3–11) and \( e_b \) is the minimum design thickness of the nozzle.

\( l \) and \( l' \)  \hspace{1cm} (Figure 6.3–11) are given by:

\[ l = 0.8 \cdot \sqrt{(d_i + e_b) \cdot e_b} \]  \hspace{1cm} (51)

\[ l' = 0.8 \cdot \sqrt{(d_i + e_b) \cdot e_b} \]  \hspace{1cm} (52)

For a pair of openings:

- \( d \) is the mean diameter of the openings or the mean equivalent diameter of the nozzle;
- \( k \) is the distance between the centres of the openings.

Where there are multiple openings, each opening shall be checked as an isolated opening and every pair of openings shall be checked.

Figure 11 — Reinforcement area A
6.3.7 Flanges and boltings

6.3.7.1 General

This clause gives rules for the design of circular bolted flange connections as shown in Figure 12, subject to internal pressure. For all other types of flanges reference should be made to EN 13445-3:2002.

![Flange working forms](image)

a) Narrow-face flange design, smooth bore
b) Narrow-face flange design, stepped bore
c) Full-face flange design (soft gasket)
d) Full-face metal / metal contact and an O-ring seal

Figure 12 — Flange working forms

Both flanges of a mating pair shall be designed to the same standard or set of rules. This applies too when one of the pairs is bolted flat end or cover.

A flange is attached to and supported by a nozzle neck, pipe or vessel wall, which will be referred to as a shell. Any fillet radius between flange and hub or shell shall be not less than 0.25 g₀ and not less than 5 mm.

Hub flanges shall not be made by machining the hub directly from plate material without special consideration.

6.3.7.2 Definitions

Bolting-up condition: This condition applies when the gasket or joint contact surface is seated during assembly of the joint at ambient temperature and with the only loading coming from the bolts.

Operating condition: The condition when the end force due to the design pressure acts on the flange.

Narrow-faced flanges: These are flanges where all the face contact area lies inside the circle enclosed by the bolts.

Full-faced flanges: These are flanges where the face contact area, either direct or via a gasket or spacer, extends outside the circle enclosing the bolts.

6.3.7.3 Symbols and units

\[ A \] outside diameter of the flange or, where slotted holes extend to outside of flange, the diameter to bottom of slots

\[ A_B \] total cross-sectional area of bolts at the section of least diameter under load

\[ A_{B,\text{min}} \] total required cross-sectional area of bolts

\[ B \] inside diameter of flange
basic gasket or joint seating width = \( w/2 \) with the exception of the ring-joint for which \( b_0 = w/8 \)

effective gasket or joint seating width, \( b = b_0 \) when \( b_0 < 6.3 \text{ mm} \), \( b = 2.52 \sqrt{b_0} \) when \( b_0 > 6.3 \text{ mm} \)

\[ C \]

bolt circle diameter

\[ C_F \]

bolt pitch correction factor
\[
C_F = \sqrt{\frac{\text{bold - spacing}}{2 \cdot d_b + \frac{6 \cdot e}{m + 0.5}}}
\]

where "bold spacing" is the distance between bolt centre lines (if calculated value < 1, \( C_F = 1 \))

\[ D \]

inside diameter of shell

\[ d_b \]

bolt outside diameter

\[ G \]

assumed diameter of gasket load reaction. When \( b_0 < 6.3 \text{ mm} \), \( G \) = mean diameter of gasket contact face; when \( b_0 < 6.3 \text{ mm} \), \( G \) = outside diameter of gasket contact face less \( 2 \cdot b \)

\[ g_0 \]

thickness of hub at small end

\[ g_1 \]

thickness of hub at batch of flange

\[ H \]

total hydrostatic end force, \( 0.785 \cdot G \cdot p \)

\[ H_D \]

hydrostatic end force applied via shell to flange, \( = 0.785 \cdot B^2 \cdot p \)

\[ H_T \]

hydrostatic end force due to pressure on flange face = \( H - H_D \)

\[ H_G \]

compression load on gasket to ensure tight joint, \( = 6.28 \cdot b \cdot G \cdot m \cdot p \)

\[ h \]

hub length

\[ h_0 \]

radial distance from bolt circle to circle on which \( H_D \) acts = \( (C - B - g_1)/2 \) except for stepped bore flanges for which \( h_0 = (C - B)/2 \)

\[ h_{D3} \]

radial distance from gasket load reaction to bolt circle, \( (C - G)/2 \)

\[ h_T \]

radial distance from bolt circle to circle on which \( H_T \) acts, \( = (2C - B - G)/4 \)

\[ k \]

stress factor

\[ K \]

\[
= \frac{A}{B}
\]

\[ M \]

= \( M_{amb} \cdot C_b/B \) (bolting-up condition) or \( M_{op} \cdot C_F/B \) (operating condition)

\[ M_{amb} \]

total moment acting upon flange for bolting-up condition

\[ M_{op} \]

total moment action upon flange for operating condition

\[ m \]

gasket factor (Table 6.3–1)

\[ w \]

contact width of gasket, as limited by gasket width and flange facing

\[ p_c \]

calculation pressure

\[ f_{b,amb} \]

bolt nominal design stress at atmospheric temperature (see 6.3.7.5)

\[ f_B \]

bolt nominal design stress at design temperature (see 6.3.7.5)

\[ f_{amb} \]

design stress of flange material at ambient temperature

\[ f \]

design stress of flange material at design temperature

\[ f_{H,amb} \]

lower of design stresses of hub and shell materials at ambient temperature
6.3.7.4 Use of standard flanges

PN designated flanges according to EN 1092-1 or Class designated flanges according to EN 1759-1 may be used as pressure vessel components without any calculation, provided the following conditions are fulfilled:

a) under normal operating conditions, the calculation pressure does not exceed the rating pressure for the calculation temperature, according to the values given in EN 1092-1 for PN designated flanges or in EN 1759-1 for Class designated flanges, for the flange and the material under consideration;

b) under testing conditions or exceptional operating conditions, the calculation pressure does not exceed 1.5 times the rating pressure given in the same tables, at appropriate temperature;

c) gasket is one of the non metallic flat types with or without jacket;

d) bolts are at least of the low strength category ($R_{p, \text{bolt}} / R_{p, \text{flange}} \geq 1$).

6.3.7.5 Requirements for bolting

There shall be at least four bolts.

If steel bolts or studs smaller than 12 mm are to be used, the bolting material shall have a design stress at 50 °C of more than 150 N/mm².

Recommended bolt stresses for determining the minimum bolt area are:

a) for carbon and other non-austenitic steel, the lesser of $R_{p,0,2} / 3$ measured at design temperature and $R_{m} / 4$ measured at room temperature;

b) for austenitic stainless steel, $R_{m} / 4$ measured at design temperature;

c) these allowable stresses may be multiplied by 1.5 at test conditions.

The bearing surface for the nuts shall be parallel to the flange face to within 1°. Any back facing or spot facing to accomplish this shall not reduce the flange thickness or hub thickness below design values. The radius between the back of the flange and the hub or shell shall be maintained.

The surface finish of the gasket contact face should be in accordance with the gasket manufacturer’s recommendations if any or be based on experience.
6.3.7.6 Narrow-faced gasketed flanges

6.3.7.6.1 General

For calculation the "loose method" is used in which the flange is assumed to get no support in bending from the shell and correspondingly imposes no bending stresses on it. The loose method can only be applied, if all of the following requirements are met:

a) \( g_0 \leq 16 \) mm
b) \( p \leq 2 \) N/mm\(^2\)
c) \( B / g_0 \leq 300 \).

If this is not the case the "integral method" shall apply (see EN 13445–3:2002).

![Diagram of narrow-faced gasketed flanges](image)

a) Smooth bore  b) Stepped bore

**Figure 13 — Narrow-faced gasketed flanges**

6.3.7.6.2 Bolt loads and areas

Bolt loads and areas shall be calculated for both the bolting-up and operating conditions.

a) Bolting-up condition. The minimum bolt load is given by

\[
W_{\text{amb}} = 3,14 \cdot h \cdot G \cdot y
\]  \hspace{1cm} (53)

b) Operating condition. The minimum bolt load is given by

\[
W_{\text{op}} = H + H_i
\]  \hspace{1cm} (54)

The required minimum bolt area \( A_{B,\text{min}} \) is given by

\[
A_{B,\text{min}} = \text{MAX} \left( \frac{W_{\text{op}}}{f_B}, \frac{W_{\text{amb}}}{f_{B,\text{amb}}} \right)
\]  \hspace{1cm} (55)
6.3.7.3 Flange moments

Flange moments shall be calculated for both the bolting-up and operating conditions.

a) Bolting-up condition. The total flange moment shall be:

\[ M_{\text{amb}} = W \cdot h_G \]  
(56)

b) Operating condition. The total flange moment shall be:

\[ M_{\text{op}} = H_D \cdot h_D + H_T \cdot h_T + H_G \cdot h_G \]  
(57)

6.3.7.4 Flange stresses and stress limits

Flange stresses shall be determined for both bolting-up and operating conditions from the moment, \( M \), as follows, where:

\[ M = M_{\text{amb}} \frac{C_F}{B} \]  
(58)

\[ M = M_{\text{op}} \frac{C_F}{B} \]  
(59)

for the bolting up and operating conditions respectively.

Tangential flange stress

\[ \sigma_\theta = \frac{\beta_\theta \cdot M}{e^2} \]  
(60)

Design stresses are the nominal design stresses \( f \) as defined in 6.3.2.4, except that the \( R_m / 3 \) alternative for austenitic stainless steel is not allowed.

The flange stresses as calculated above shall not exceed the following values:

operating condition: \( k \cdot \sigma_\theta \leq f \);

bolting up condition: \( k \cdot \sigma_\theta \leq f_{\text{amb}} \);

If \( B \leq 1 \, 000 \, \text{mm} \), \( k = 1,0 \).

6.3.7.7 Full-faced flanges with soft ring type gasket

6.3.7.7.1 General

This design method is applicable for full-faced flanges with non-metallic gasket not less than 1,5 mm thick and extending beyond the circle, enclosing the bolt holes.
Key:
See 6.3.7.7.2

Figure 14 — Full-faced flanges with soft ring type gasket

6.3.7.7.2 Additional symbols

- $A_1$: inside diameter of gasket contact face;
- $b_0'$: basic gasket seating width effective under initial tightening up = lesser of $(G_0 - C)$ and $(C - A_1)$;
- $b'$: effective gasket seating width = $4 \cdot \sqrt{b_0'}$ (This expression is valid only with dimensions expressed in millimetres);
- $2b''$: effective gasket pressure width, taken as 5 mm;
- $G$: diameter at location of gasket load reaction, = $C - (d_h + 2b'')$;
- $G_0$: outside diameter of gasket or outside diameter of flange, whichever is less;
- $H$: total hydrostatic end force, = $0.785 \cdot (C - d_h)^2 \cdot p$;
- $H_R$: balancing reaction force outside bolt circle in opposition to moments due to loads inside bolt circle;
- $h_T$: radial distance from bolt circle to circle on which $H_G$ acts, = $(d_h + 2b'')/2$;
- $h_R$: radial distance from bolt circle to circle on which $H_R$ acts, = $(G_0 - C + d_h)/4$;
- $h_S$: radial distance from bolt circle to circle on which $H_T$ acts, = $(C + d_h + 2b'' - B)/4$;
\( M_R \) balancing radial moment in flange along line of bolt holes;

\( n \) number of bolts.

### 6.3.7.7.3 Bolt loads and areas

Bolt loads shall be calculated, taking:

\[
W_{op} = H + H_G + H_R \tag{61}
\]

where

\[
H_R = \frac{M_R}{h_R} \tag{62}
\]

\[
M_R = H_D \cdot h_D + H_T \cdot h_T + H_G \cdot h_G, \tag{63}
\]

\[
W_{amb} = 3.14 \cdot C \cdot b' \cdot y \tag{64}
\]

### 6.3.7.7.4 Flange design

The flange thickness shall be not less than the value of \( e \) from the following equation:

\[
e = \frac{6 \cdot M_R}{\sqrt{f \cdot (3.14 \cdot C - n \cdot d_h)}} \tag{65}
\]

The bolt spacing shall not exceed:

\[
2 \cdot d_b + \frac{6 \cdot e}{m + 0.5} \tag{66}
\]

### 6.3.7.8 Full face flanges with metal to metal contact

#### 6.3.7.8.1 General

The rules shall be applied when there is metal to metal contact both inside and outside the bolt circle before the bolts are tightened with more than a small amount of preload and the seal is provided by an O-ring or equivalent. Manufacturing procedures and tolerances shall ensure that the flange is not dished so as to give initial contact outside bolt circle.

It is assumed that a self-sealing gasket is used approximately in line with the wall of the attached pipe or vessel and that the gasket seating load and any axial load from the seal may be neglected.
Figure 15 — Full face flange with metal to metal contact

6.3.7.8.2 Additional symbols

$G$ mean diameter of gasket

$H_R$ balancing reaction force outside bolt circle in opposition to moments due to loads inside bolt circle;

$h_R$ radial distance from bolt circle to circle on which $H_R$ acts, $h_R = (A - C)/2$;

$M_R$ balancing radial moment in flange along line of bolt holes;

$n$ number of bolts.

6.3.7.8.3 Design

The following rules apply where the flange is to be bolted to an identical flange or to a flat cover.

Bolt loads shall be calculated in accordance with 6.3.7.6.2 taking:

$$W_{op} = H + H_R$$  \hspace{1cm} (67)

where

$$H_R = M_R / h_R$$  \hspace{1cm} (68)

$$M_R = H_{12} h_b + H_{1} h_t$$  \hspace{1cm} (69)

$$W_{amb} = 0$$

The flange thickness shall be not less than:

$$e = \sqrt{\frac{6 \cdot M_R}{f \cdot (3.14 \cdot C - n \cdot d_h)}}$$  \hspace{1cm} (70)
7 Manufacturing and welding

7.1 Introduction

In case of matters not covered by this clause reference should be made to EN 13445-3:2002, EN 13445-4:2002, EN 13445-5:2002, where applicable.

7.2 General

Expansion vessels shall be manufactured according to approved drawings and specifications observing the requirements of this European Standard and sound engineering practice.

Workshops and equipment shall be adequate for the construction of the vessels and shall also allow their testing and inspection. The manufacturer has the responsibility for the competence, training and supervision of his staff.

In order to realise the specified quality of the finished expansion vessel or part of it the manufacturer shall make sure that the manufacturing procedure chosen is adequate for the purpose envisaged.

It is the responsibility of the manufacturer to operate a recognized formal system for the control of manufacturing operations which includes special process such as forming, welding, clenching etc., and which assures the appropriate traceability of materials.

7.3 Manufacturing tolerances

7.3.1 General

The geometry of welded butt and fillet joints shall comply with EN 13445-3:2002 except as modified below for shell longitudinal and circumferential seams. If the drawings of expansion vessels require more stringent manufacturing tolerances they supersede the requirements given in this clause.

7.3.2 Middle line and surface alignment

For longitudinal joints in cylinders and spherical components (whether of equal or different thicknesses) the middle lines of adjacent plates shall have a maximum misalignment \( d_1 \) (\( e_1 \) being the thinner plate thickness) according to Table 4.

<table>
<thead>
<tr>
<th>( e_1 )</th>
<th>( d_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 2 \leq e_1 \leq 4 )</td>
<td>( e_1 / 4 )</td>
</tr>
<tr>
<td>( 4 &lt; e_1 \leq 10 )</td>
<td>1</td>
</tr>
<tr>
<td>( 10 &lt; e_1 \leq 30 )</td>
<td>( e_1 / 10 )</td>
</tr>
</tbody>
</table>
For circumferential joints the middle lines of adjacent plates (whether of equal or different thicknesses) shall have a maximum misalignment \( d_1 = \frac{e_1}{10} + 1 \) mm. \( e_1 \) being the thinner plate thickness.

![Figure 16 — Middle line and surface misalignment](image)

For longitudinal joints in cylinders the surfaces of adjacent plates shall have a maximum misalignment of \( d_2 = \frac{e_1}{4} \) but not more than 3 mm. \( e_1 \) being the thinner plate thickness.

For longitudinal joints in spherical components as well as for circumferential joints the surfaces of adjacent plates shall have a maximum misalignment of \( d_2 = \frac{e_1}{4} \), \( e_1 \) being the thinner plate thickness.

If the misalignment tolerances are exceeded surfaces shall be tapered with a slope on 1 in 4 over a width that includes the width of the weld, the lower surface being built up with added weld metal if necessary to provide the required taper. Trimming of plate surfaces is not permitted where this reduces the thickness below the required minimum.

### 7.3.3 Tolerances for vessels

#### 7.3.3.1 For cylindrical and spherical vessels the mean external diameter derived from the circumference shall not deviate by more than 1.5% from the specified external diameter.

#### 7.3.3.2 Out-of-roundness defined by the following equation:

\[
O = \frac{D_{\text{max}} - D_{\text{min}}}{\frac{D_{\text{max}} + D_{\text{min}}}{2}} \times 100 \% \quad (71)
\]

shall not exceed:

- 1.5% for \( e/D < 0.01 \);
- 1.0% for \( e/D \geq 0.01 \).

#### 7.3.3.3 The deviation from the straight line shall not be more than 0.5% of the total cylindrical length of the vessel.

#### 7.3.3.4 Regularities in profiles occurring at longitudinal welding seams and associated with "flats" adjacent to the weld or "peakings" shall not exceed 5 mm.

#### 7.3.3.5 Dished ends shall be aligned with the tolerances as laid down below except that the crown radius shall not be greater than specified in the design and the knuckle radius shall not be less than specified in the design.
Table 5 — Tolerances for dished ends

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Range of application</th>
<th>Limit deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference C ($C = \pi \times D$)</td>
<td>$D_e \leq 300$ mm</td>
<td>$\pm 4$ mm</td>
</tr>
<tr>
<td></td>
<td>Ferritic materials:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$300$ mm $&lt; D_e \leq 1000$ mm:</td>
<td>$\pm 0.4%$</td>
</tr>
<tr>
<td></td>
<td>$1000$ mm $&lt; D_e$:</td>
<td>$\pm 0.3%$</td>
</tr>
<tr>
<td></td>
<td>Austenitic materials:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$300$ mm $&lt; D_e$:</td>
<td>$+0.5%, -0.7%$</td>
</tr>
<tr>
<td>Out-of-roundness $O$</td>
<td>all</td>
<td>$\leq 1%$</td>
</tr>
<tr>
<td>Inner height $H$</td>
<td>all $D_e$, but not less than $+10$ mm</td>
<td></td>
</tr>
<tr>
<td>Wall thickness $e$ (nominal)</td>
<td>$e \leq 10$ mm:</td>
<td>$-0.3$ mm</td>
</tr>
<tr>
<td></td>
<td>$10$ mm $&lt; e$:</td>
<td>$-0.5$ mm</td>
</tr>
<tr>
<td>Deviation from cylindrical shape $\alpha$</td>
<td>all</td>
<td>$\alpha_0 \leq 2^\circ$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha_0 \leq 5^\circ$</td>
</tr>
<tr>
<td>Straight flange $h_1$</td>
<td>all</td>
<td>$3 \times e$</td>
</tr>
</tbody>
</table>

7.4 Weld details

7.4.1 Recommended weld details

Recommended weld details are given in EN 1708-1.

The manufacturer in selecting an appropriate weld detail should give consideration to:

— method of manufacture;
— service conditions;
— ability to carry out the necessary NDE.

Other weld details may be used provided their suitability is proven by procedure approval to EN ISO 15614-1:2004 and EN ISO 15613:2004.
7.4.2 Vessels made in more courses

Where any part of a vessel is made in two or more courses the longitudinal weld seams of adjacent courses shall be staggered by \( 4e \) with 10 mm minimum, measuring the distance between the edges of the longitudinal joints.

7.4.3 Joggle joints

Joggle joints may be used on expansion vessels under the following conditions:

- operating temperature is between –10 °C and +70 °C and
- for circumferential joints only, with wall thicknesses not exceeding 8 mm and
- maximum diameter not exceeding 2 000 mm.

![Figure 18 — Details of joggle joint](image)

7.5 Welding

7.5.1 General

Welding of joints for parts of a vessel shall only be undertaken if the following conditions are satisfied:

a) welding procedure specification is compiled by the manufacturer;
b) welding procedures selected by the manufacturer are qualified for the field of application;
c) welders and welding operators are qualified for the work allocated to them and their approval is valid.

7.5.2 Welding procedure specification (WPS)

The manufacturer shall compile welding procedure specifications, in accordance with EN ISO 15609-1:2004 for each joint or family of joints.

7.5.3 Qualification of WPS

Welding procedure qualification tests in accordance with EN ISO 15614-1:2004 or EN ISO 15613:2004 shall be carried out to cover the welding procedure specifications and are to be recorded in a welding procedure approval record (WPAR).

7.5.4 Qualification of welders and welding operators

Welders and welding operators shall be approved to EN 287-1:2004 or EN 1418:1997 respectively. An up-to-date list of welders and welding operators together with their records of approval test shall be maintained by the manufacturer.
7.5.5 Preparation of edges to be welded

The edges to be welded shall be kept in position, either by mechanical means, and/or by tack welds. The tack welds shall be removed or fused again in the weld bead in such a way that no metallurgical or homogeneity defects are generated.

When welding without a sealing run, the manufacturer shall ensure the required penetration at the weld root.

The surface to be welded shall be thoroughly cleaned of foreign substance.

7.5.6 Execution of welded joints

After each weld run, the slag shall be removed and the weld cleaned and the surface defects removed.

Unless the welding process used provides effective and sound penetration, the second side of a welded joint shall be removed back to sound metal.

7.5.7 Attachments, supports and stiffeners

Attachments, whether temporary or not, supports and stiffeners shall be welded to a part subject to pressure by qualified welders using a qualified procedure.

Temporary attachments shall be removed using a technique which does not affect the properties of the metal of the pressure part to which they are welded.

7.6 NDE personnel

NDE personnel shall be qualified and certified according to EN 473:2000.

NOTE For pressure equipment in categories III to IV the personnel need to be approved by a recognized third-party.

7.7 Manufacture and testing of permanent joints

7.7.1 Welded joints

7.7.1.1 General

In order to control the compliance of the welded joints with the specification production test plates shall be welded and tested in accordance with the requirements detailed below, for a joint or family of joints of the main shell longitudinal and circumferential welds.

7.7.1.2 Reference criteria

The number of the production test plates and the extent of their testing depend on the length of the welded joints, the material thickness and the weld joint coefficient $z$ for each qualified welding procedure as follows:

7.7.1.2.1 For vessels with $z = 0.7$ no test plates are required.

7.7.1.2.2 For vessels with $z > 0.7$ the following shall apply:

a) one test plate per vessel in the case of $z = 1.0$;

b) one test plate per 500 m of longitudinal joints in the case of $z = 0.85$;

c) where the circumferential seams are welded to a procedure different to the longitudinal seams, one test plate per year.

After 10 test plates having successfully passed the tests testing may be reduced to the following:
d) one test plate per 100 m of longitudinal joints in the case of \( z = 1.0 \);

e) one test plate per 2 500 m of longitudinal joints in the case of \( z = 0.85 \).

### 7.7.1.2.3

For vessels whose design is verified by experimental design methods, regular tests performed on vessels taken from the production cover the performance of tests of welded joints.

### 7.7.1.2.4

When a vessel includes one or more longitudinal seams the test plates should wherever practicable be attached to the shell plate on one end of one seam so that the edges to be welded in the test plate are a continuation and duplication of the corresponding edges of the longitudinal seams. The weld metal should be deposited in the test plates continuously with the welding of the corresponding longitudinal seam so that the welding process, procedure and technique are the same. When it is necessary to weld the test plates separately, the procedure used should duplicate that used in the construction of the vessel.

When the test plates are required for circumferential welds they may be welded separately from the vessel providing the technique used in their preparation duplicates as far as possible the procedure used in the welding of the appropriate seams of the vessel.

### 7.7.1.3 Testing on test plates

The type and number of specimens to be taken from the test plate shall be to the requirements given below.

#### Table 6 — Test specimens

<table>
<thead>
<tr>
<th>Designation</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face bend test to EN 910:1996</td>
<td>FB</td>
</tr>
<tr>
<td>Root bend test to EN 910:1996</td>
<td>RB</td>
</tr>
<tr>
<td>Transverse tensile test to EN 895:1995</td>
<td>TT</td>
</tr>
<tr>
<td>Macro examination</td>
<td>Ma</td>
</tr>
</tbody>
</table>

#### Table 7 — Testing of production test plates

<table>
<thead>
<tr>
<th>Group</th>
<th>Test specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steels (1.;1.1)</td>
<td>1 FB, 1 RB, 1 Ma</td>
</tr>
<tr>
<td>Austenitic steels (8.1)</td>
<td>1 FB, 1 RB, 1 TT, 1 Ma</td>
</tr>
</tbody>
</table>

### 7.7.1.4 Performances of tests

#### 7.7.1.4.1 General

The individual test pieces shall be manufactured, tested and meet the acceptance criteria defined below:

#### 7.7.1.4.2 Transverse tensile test (TT)

Unless otherwise specified the tensile strength shall meet the minimum value for the parent metal.

Where the weld metal and/or welded joint properties are specified below those of the base metal by design, special consideration is needed.

#### 7.7.1.4.3 Bend test (FB / RB)

The testing and the test requirements shall comply with 7.4.2 of EN ISO 15614-1:2004.
7.7.1.4.4 Macro examination (Ma)

The macro etch shall show sound built-up of beads and sound penetration.

7.7.1.4.5 Test record

A test record shall be prepared indicating compliance of the results with the specified requirements as per example in EN ISO 15613:2004.

7.7.1.4.6 Retests

Production factors may result in a scatter of mechanical test results which may fall below the agreed specification level. Where individual tests do not comply with the above requirements the reasons for this failure shall be investigated and if no unacceptable imperfections are found the following retests should be made:

a) tensile test: two retests;

b) bend test: two retests.

Should any of the retests fail to comply with the requirements then the joints represented by the test plate shall be deemed not in compliance with this European Standard.

7.7.1.5 NDE of welded joints during manufacture

7.7.1.5.1 General

As an alternative to the welding and testing of production test plates NDE in the form of radiographic or ultrasonic examination may be used to check the required quality of the vessel welds.

For the following vessels no NDE is required:

a) vessels with a weld joint coefficient \( z = 0.7 \);

b) vessels whose design is verified by experimental design methods. See also 7.7.1.2.3.

7.7.1.5.2 Radiography

The examination shall apply according to class B of EN 1435:1997 and with the following modalities for each qualified welding procedure:

a) one film of 200 mm per vessel including one T-junction in the case of \( z = 1.0 \);

b) one film of 200 mm including one T-junction per 500 m of longitudinal joints in the case of \( z = 0.85 \);

c) where the circumferential seams are welded to a procedure different to the longitudinal seams, one film of 200 mm including one T-junction per year. After 10 films plates having fulfilled the acceptance criteria testing may be reduced to the following:

d) one film per 100 m of longitudinal joints in the case of \( z = 1.0 \);

e) one film per 2,500 m of longitudinal joints in the case of \( z = 0.85 \).

Acceptance criteria for radiography are to be taken from EN 13445-5.
7.7.2 Clenched joints

For vessels whose design is verified by the experimental design method, regular tests performed on vessels taken from the production cover the performance of tests of clenched joints.

At least tests according to 6.2.3 or 6.2.4 have to be carried out per change of construction parameters.

7.8 Forming of parts subject to pressure

7.8.1 Ratio of deformation

7.8.1.1 Dished circular products

The following equation shall be used for the calculation of deformation (F) for all finished circumferential products (e.g. dished ends, spherical caps).

\[ F = 100 \ln \left( \frac{D_b}{D_e} - 2e \right) \% \]  \hspace{1cm} (72)

where

- \( e \) is the thickness of the initial product;
- \( D_b \) is the diameter of the blank or diameter of intermediate product.

In case of different forming steps without intermediate heat treatment, the initial diameter is to be applied. In case of intermediate heat treatment, the diameter after the last heat treatment is relevant;

- \( D_e \) is the external diameter of the finished product;
- \( \ln \) is the naperian logarithm.

\[ a) \text{ Initial product} \hspace{1cm} b) \text{ Intermediate product} \hspace{1cm} c) \text{ Final product} \]

Figure 19 — Ratio of deformation of dished circular products
7.8.1.2 Cylinders made by rolling

The following equation shall be used for the calculation of deformation \((F)\) for rolled products:

\[
F = \frac{50 \cdot e}{R_m} \left(1 - \frac{R_m}{R_{m0}}\right) \ [\%] \tag{73}
\]

where

- \(e\) is the thickness of the initial product;
- \(R_{m0}\) is the mean radius of the initial product.

In case of different forming steps without intermediate heat treatment, the ratio of deformation is the total amount of the ratio of deformation of the individual forming steps. In case of intermediate heat treatment, the deformation is that deformation achieved after the last previous heat treatment;

- \(R_m\) is the mean radius of the finished product.

![Diagram of rolled cylinders](image)

Figure 20 — Ratio of deformation of rolled cylinders

7.8.1.3 Tube bends

The following equation shall be used for the calculation of deformation \((F)\) of tube bends:
\[ F = 100 \cdot \frac{D_e}{2R} \% \] (74)

where

\[ R \] is the radius of curvation for the tube;
\[ D_e \] is the external diameter of the tube.

Figure 21 — Ratio of deformation for tubes

7.8.1.4 Other part types

For all other types of parts reference should be made to EN 13445-4:2002.

7.8.2 Forming conditions

7.8.2.1 Cold forming

Cold forming of ferritic steels as given in Clause 5 is defined as forming at temperatures below the maximum permissible temperature for stress relieving minus (20 to 30) °C in accordance with the applicable material standards.

Cold forming of austenitic steels is defined as forming at temperature below 300 °C.

7.8.2.2 Hot forming

Hot forming of carbon steels shall be carried out at temperatures above the maximum permissible temperature for stress relieving, usually in the temperature range of normalising, in accordance with the material specifications.

For austenitic steels of group 8.1 hot forming shall be carried out at a temperature of 300 °C or above.

7.8.3 Heat treatment

7.8.3.1 Heat treatment after cold forming of flat parts

If \( F > 5 \% \), post forming heat treatment is required with the following exceptions:
— torispherical dished ends \( \{ (\text{flange radius} \geq 0.1D_e \text{ and crown radius} \geq D_e \} \) with \( e \leq 8 \text{ mm and } h \leq 40 \text{ mm} \); 

— austenitic steels of group 8.1; 

— vessel and vessel parts whose design is proven by experimental design methods.

### 7.8.3.2 Heat treatment after cold forming for tubular products

Post forming heat treatment is required:

— if curvature radius \( R \leq 1.3D_e \) or

— if \( 1.3 \cdot D_e < R < 2.5D_e \) and if external tube diameter \( D_e > 142 \text{ mm} \).

### 7.8.3.3 Heat treatment after hot forming

Heat treatment after hot forming is not required for materials falling into groups 1.1.1 and 8.1.

### 7.8.4 Visual examination and control of dimensions

Formed pressure parts shall be subject to visual examination and dimensional check in the delivery condition. The results of the visual examination and the check of dimensions shall be certified in the certificate.

### 7.8.5 Test certificate

Formed parts for pressure vessels shall be accompanied by an inspection document according to vessel category.

Where applicable the following information shall be recorded:

a) type of heat treatment;

b) correct state of heat treatment;

c) correct transfer of marking, if required.

### 7.9 Repairs

#### 7.9.1 Surface defects

Vessel surfaces have to undergo a visual check after production.

The surfaces shall be smooth. Irregularities are accepted if they do not influence the appropriate use of the vessels.

#### 7.9.2 Repairs, elimination of defects

All unacceptable imperfections are to be removed by mechanical or thermal means, whereby the minimum thickness of the surface has to be maintained.

Repair weldings may only be carried out by qualified welders within the framework of approved WPS.

### 7.10 Finishing operations

Finishing operations are all operations carried out after the vessel has been pressure tested and before shipment/transport.
Any repairs, thermal or mechanical operations shall be followed by the pressure test (see 9.5).

8 Diaphragm

8.1 General

As an integral part of the expansion vessel the diaphragm separates the vessel into a water space and a gas space. A distinction is drawn between (closed) bag-type diaphragms and (open) cup-type diaphragms. The latter are stressed primarily by deflexion, the former by extension.

NOTE The diaphragm separates water and gas both of which are under the same pressure. Therefore the diaphragm is not a pressure bearing part.

8.2 Materials

Materials used for diaphragm shall be suitable for the intended purpose and comply with the tests specified in this clause. These tests are valid for all applications where the water in the vessel normally does not exceed 70 °C and is not lower than 5 °C.

For applications where the vessel water temperature is normally outside the range of 5 °C to 70 °C the test methods in this clause shall be adapted in such a way that the test temperature corresponds to the temperature, requirements to which the diaphragm will be subject during operation.

Diaphragms for water with antifreeze additives shall be tested with the corresponding water solution. This is not necessary if a declaration of the diaphragm manufacturer confirms the suitability of the material.

8.3 Hygienic demands

Diaphragms for vessels intended for drinking water systems are not to affect the quality of the water.

NOTE For the time being materials in contact with drinking water have to comply with the respective national regulations.

8.4 Test concept

The test program in this standard falls into 2 categories:

— tests on the diaphragm material according to 8.5.1;

— tests on the diaphragm, built into the vessel, according to 8.5.2 and 8.5.3.

Out of a range of vessels similar in design and geometrical proportions two vessels sizes are selected whose diaphragm would be stressed the most when compared with other vessels in the range.

Standards to be used for the tests are contained in Annex A and can be selected by making reference to the test number.

8.5 Testing

8.5.1 General

For each vessel size/type selected for testing two whole vessels taken from production and two corresponding diaphragms are to be provided.

8.5.2 Tests on diaphragms

One unused diaphragm per vessel size/type selected is to be used for tests according to Table 8.5–1.
Table 8 — Tests on diaphragms

<table>
<thead>
<tr>
<th>Test number</th>
<th>Property to be tested</th>
<th>Requirements for cup-type diaphragms</th>
<th>Requirements for bag-type diaphragms</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5.2.1</td>
<td>Thickness</td>
<td>Not less than 1 mm at any point</td>
<td>Not less than 1 mm at any point</td>
</tr>
<tr>
<td>8.5.2.2</td>
<td>Visual surface inspection</td>
<td>No cracks, foreign inclusions or blisters</td>
<td>No cracks, foreign inclusions or blisters</td>
</tr>
<tr>
<td>8.5.2.3</td>
<td>Tensile strength at break</td>
<td>&gt; 10 N/mm²</td>
<td>&gt; 10 N/mm²</td>
</tr>
<tr>
<td>8.5.2.4</td>
<td>Elongation at break</td>
<td>&gt; 450 %</td>
<td>&gt; 450 %</td>
</tr>
<tr>
<td>8.5.2.5</td>
<td>Shore A hardness</td>
<td>50 to 65 Shore A</td>
<td>45 to 65 Shore A</td>
</tr>
<tr>
<td>8.5.2.6</td>
<td>Compression set in air</td>
<td>≤ 40 %</td>
<td>≤ 60 %</td>
</tr>
<tr>
<td>8.5.2.7</td>
<td>Specific mass (tolerance)</td>
<td>± 0,03 g/cm³</td>
<td>± 0,03 g/cm³</td>
</tr>
</tbody>
</table>

Minimum requirements given in 8.5.2.1 to 8.5.2.7 are valid for proven materials as listed in Annex B.

For new materials or derivatives of proven materials minimum requirements are to be defined by the diaphragm manufacturer on the basis of the results of appropriate tests.

The second unused diaphragm shall undergo an ageing test.

The diaphragm is immersed in water with a temperature of 70 °C ± 5 °C for 28 days. After 28 days the tests 8.5.2.8, 8.5.2.9 and 8.5.2.10 are carried out. The test results shall be within the limits given in Table 9 when compared with the results obtained on the first diaphragm.

Table 9 — Limits for results of ageing test

<table>
<thead>
<tr>
<th>Test number</th>
<th>Property to be tested</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5.2.8</td>
<td>Tensile strength at break</td>
<td>≤ 25 %</td>
</tr>
<tr>
<td>8.5.2.9</td>
<td>Elongation at break</td>
<td>≤ 25 % (rel.)</td>
</tr>
<tr>
<td>8.5.2.10</td>
<td>Shore A hardness</td>
<td>≤ 5 shore A</td>
</tr>
</tbody>
</table>

Diaphragms for fresh water application do not need to undergo an ageing test if the vessel plate explicitly limits the max. operating temperature to 40 °C.

8.5.3 Cyclic stressing on vessels

8.5.3.1 General

One vessel per each selected size is subjected to continuous cyclic stressing. Pressurised water is pumped in the vessel until it is filled to 50 % of the content of the chamber where the membrane expands and then released again.

8.5.3.2 For heating expansion vessels the test is performed at a water temperature of 70 °C ± 5 °C. The number of cycles depends on the vessel volume and can be read from Figure 22.

Linear interpolation of values is permitted.
8.5.3.3 For drinking water expansion vessels the test is performed at ambient water temperature. The number of cycles depends on the vessel volume and can be read from Figure 8.5–2. Linear interpolation of values is permitted.

Figure 22 — Cyclic stressing for heating expansion vessels

Figure 23 — Cyclic stressing for drinking water expansion vessels
8.5.3.4 In respect to the characteristics of the test cycles the minimum time values in Figure 24 have to be observed.

![Diagram](image)

**Key**

- a, c minimum 20 s
- b, d minimum 10 s

Figure 24 — Time characteristics of test cycles

8.5.3.5 **Acceptance criteria**

After the cyclic test, once the vessel has cooled down, the gas side of the vessel is filled with air to 1,5 bar. The pressure drop within the following hour shall not exceed 0,15 bar.

Changes in ambient temperature shall be taken into account.

8.5.4 **Diaphragm permeability test**

This test is performed on a second vessel of each size selected. It is carried out by measuring the pressure drop in both of them after 28 days at a temperature of 20 °C. The initial pressure is the admissible operating pressure. The pressure drop shall not exceed 2 % for vessels of ≤ 100 l during this time. With vessels > 100 l it shall not exceed 1 % of the initial pressure. Air is to be used as the testing gas. Changes in ambient temperature shall be taken into account.

8.5.5 **Repetition of tests**

Two repeat tests have to be made for each failed test. Both shall be successful.

8.5.6 **Test report**

A report on the results of all the tests is to be drawn up.
8.6 Tests by the diaphragm manufacturer

Per batch (series) of diaphragms of the same size and material the manufacturer conducts the tests according to 8.5.2.1 to 8.5.2.5 and 8.5.2.7. The results shall be recorded in a certificate according to EN 10204 and kept at the disposal of the vessel manufacturer. Once a year the diaphragm manufacturer conducts tests according to 8.5.2.6 and 8.5.2.8 to 8.5.2.10 for each type of material used.

8.7 Marking of diaphragms

Each diaphragm has to be marked in such a way that the following information (possibly encoded) is contained:

- month/year of manufacturing;
- mark of manufacturer (if diaphragm manufacturer is not the vessel manufacturer);
- size/type or code number.

9 Testing and inspection

9.1 General

Type, amount and frequency of approvals, tests and inspections described in this clause as well as the responsibilities are to be determined in accordance with EN 13445-5:2002.

9.2 Technical documentation

The manufacturer establishes a technical documentation. It is to demonstrate compliance with this European Standard and consists of:

- design calculations or data of experimental design method;
- drawings;
- technical / manufacturing schedule, covering:
  - technical data / operation of vessel;
  - manufacture;
  - welding;
  - materials;
- amount and frequency of tests / inspections during manufacturing.
9.3 Inspections during manufacturing

Purpose of these inspections is to make sure the vessels manufactured meet the requirements of this European Standard and are based on the technical documentation. They cover:

- use of correct materials/ correct transfer of stamping where applicable;
- use of agreed on welding procedures/ observation of the corresponding specifications;
- use of qualified welders/ operators;
- visual examination of welds;
- correct thermal treatment where applicable;
- internal / external examination and dimensional checks;
- establishing and testing of test plates or NDE.

9.4 Pressure test

Pressure tests are normally carried out with water. Where air is used instead of water authorisation of national safety bodies may have to be obtained in order to cover the workers safety.

The pressure test is performed at ambient temperature. The vessel is pressurised to 1.43 PS and inspected for leaks. No leaks shall occur. If the vessel leaks and is then repaired the pressure test shall be repeated.

The results of the test shall be recorded by the manufacturer.

9.5 Marking

Each vessel shall be permanently and legibly marked with the following information. Direct stamping of the vessel shell is only acceptable where the vessel walls are above 6 mm.

- Nominal volume of the vessel \( V \)
- manufacturer's name / symbol and address;
- vessel identification;
- period / year of manufacture;
- maximum allowable pressure \( PS \);
- maximum / minimum allowable operating temperature \( TS \);
- initial precharge pressure;
- space for a modified precharge pressure, if applicable;
- test pressure \( PT \).
9.6 Documentation

9.6.1 Depending on type of vessel and/or the method of production the documentation may cover one vessel only or a group/series of vessels. It shall contain the following elements:

— vessel type and/or production batch;
— technical documentation;
— records of all inspections and tests;
— reference to relevant files containing material certificates, welding procedure approvals/specifications, welder/operator qualification, welding consumables;
— report on pressure test;
— certificate of compliance.

9.6.2 Besides the documentation covering the vessel(s) the following records are to be filed:

— manufacturer’s quality system;
— material certificates;
— list of qualified welders/operators;
— welding procedure approvals;
— welding procedure specifications.

9.6.3 The vessel manufacturer is responsible for filing the records for a minimum period of 10 years.

9.6.4 With each vessel Instructions for installation and operation are to be provided.
Annex A
(informative)

Standards for testing diaphragms

Testing of diaphragms for expansion vessels has been done for many years based on ISO standards and national German DIN standards as listed below; see Bibliography.

<table>
<thead>
<tr>
<th>Standard number</th>
<th>Property to be tested on diaphragms in vessels according to EN 13831</th>
<th>Relevant test number</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 2781</td>
<td>Density</td>
<td>8.5.2.7</td>
</tr>
<tr>
<td>DIN 53504</td>
<td>Tensile strength at break, tensile strength at yield, elongation at break and stress values in tensile test</td>
<td>8.5.2.3, 8.5.2.4, 8.5.2.8, 8.5.2.9</td>
</tr>
<tr>
<td>DIN 53505</td>
<td>Shore A and Shore D hardness</td>
<td>8.5.2.5</td>
</tr>
<tr>
<td>ISO 815</td>
<td>Compression set at various temperatures</td>
<td>8.5.2.6</td>
</tr>
<tr>
<td>ISO 1817</td>
<td>Behaviour of rubber in liquids</td>
<td></td>
</tr>
<tr>
<td>ISO 23529</td>
<td>Linear dimensions of test pieces and products</td>
<td>8.5.2.1</td>
</tr>
</tbody>
</table>
Annex B
(informative)

Proven diaphragm materials

The following materials have proven suitable for diaphragms on the basis of Clause 8 in water with glycol based additives of up to 49%:

— IIR (Butyl rubber);
— NBR (Nitrile rubber);
— NR (Natural rubber);
— SBR (Styrene — butadiene rubber);
— EPDM (Ethylene — Propylene — diene rubber).
Annex ZA
(ininformative)

Relationship between this European Standard and the Essential requirements of EU Directive 97/23/EC

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Directive 97/23/EC.

Once this standard is cited in the Official Journal of the European Communities under that Directive and has been implemented as a national standard in at least one Member State, compliance with the clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive and associated EFTA regulations.

Table ZA-1 — Correspondence between this European Standard and Directive 97/23/EC

<table>
<thead>
<tr>
<th>Clause(s)/sub-clause(s) of this EN</th>
<th>Essential Requirements (ERs) of Directive 97/23/EC</th>
<th>Qualifying remarks/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Annex I, 4.1 (d)</td>
<td>Material suitable for intended processing procedure</td>
</tr>
<tr>
<td>6.1.4</td>
<td>Annex I, 2.4</td>
<td>Means of examination</td>
</tr>
<tr>
<td>6.2</td>
<td>Annex I, 2.2.4</td>
<td>Experimental method</td>
</tr>
<tr>
<td>6.3</td>
<td>Annex I, 2.2.3</td>
<td>Calculation method</td>
</tr>
<tr>
<td>6.3.2.4</td>
<td>Annex I, 7.1.2</td>
<td>Permissible membrane stress</td>
</tr>
<tr>
<td>6.3.2.5</td>
<td>Annex I, 7.2</td>
<td>Joint coefficients</td>
</tr>
<tr>
<td>7 (except 7.2)</td>
<td>Annex I, 3.1</td>
<td>Manufacturing procedures</td>
</tr>
<tr>
<td>7.4 / 7.5 / 7.7 (except 7.7.2)</td>
<td>Annex I, 3.1.2</td>
<td>Joining</td>
</tr>
<tr>
<td>7.6</td>
<td>Annex I, 3.1.3</td>
<td>Non-destructive testing</td>
</tr>
<tr>
<td>7.8.3</td>
<td>Annex I, 3.1.4</td>
<td>Heat treatment</td>
</tr>
<tr>
<td>9.3/9.4</td>
<td>Annex I, 3.2</td>
<td>Final assessment</td>
</tr>
<tr>
<td>9.5</td>
<td>Annex I, 3.3</td>
<td>Labelling and marking</td>
</tr>
<tr>
<td>9.4</td>
<td>Annex I, 7.4</td>
<td>Hydrostatic test pressure</td>
</tr>
</tbody>
</table>

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.
Bibliography


[10] EN 10130, Cold rolled low carbon steel flat products for cold forming — Technical delivery conditions


[14] EN 1759-1, Flanges and their joint — Circular flanges for pipes, valves, fittings and accessories, Class designated — Part 1: Steel flanges, NPS ½ to 24

---

4) Under revision.
BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.
Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001. Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.
Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.
Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001.
Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

Copyright subsists in all BSI publications. BSI also holds the copyright, in the UK, of the publications of the international standardization bodies. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI.

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

Details and advice can be obtained from the Copyright & Licensing Manager.
Tel: +44 (0)20 8996 7070. Fax: +44 (0)20 8996 7553.
Email: copyright@bsi-global.com.