PRESSURE TEST IN ACCORDANCE WITH
THE STANDARD DIN EN 13445

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A total of over 1000 professionals in 4 states in the Baltic region
The pressure test requirements are specified in harmonized standard EN 13445-5

EN 13445-5

Unfired pressure vessels. Part 5 : Inspection and testing

Original standard EN 13445-5 (issue 1) was approved in May 2002 and referenced in the Official Journal 17.7.2002.

Since then EN 13445-5 has been revised and amended many times.

- A total of 26 revisions (issues) to EN 13445 series of standards have been published by May 2007.
- The pressure test requirements have been revised twice by amendments to EN 13445-5
  - EN 13445-5 Amendment A2:2005 was approved and published as issue 14 in June 2005.
  - EN 13445-5 Amendment A3:2006 was approved and published as issue 20 in May 2006.

The original EN 13445-5 does not any more give presumption of conformity with the essential requirements of the Pressure Equipment Directive 97/23/EC.
PED Annex I  Essential Safety Requirements

7.4. Hydrostatic test pressure

For pressure vessels, the hydrostatic test pressure referred to in 3.2.2 must be no less than:

- that corresponding to the maximum loading to which the pressure equipment may be subject in service taking into account its maximum allowable pressure and its maximum allowable temperature, multiplied by the coefficient 1.25, or
- the maximum allowable pressure multiplied by the coefficient 1.43, whichever is the greater.

### Table

<table>
<thead>
<tr>
<th>CEN</th>
<th>Standard Code</th>
<th>Date Expired</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 13445-5:2002</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>EN 13445-5:2002/A3:2006</td>
<td>Note 3</td>
<td>Date Expired (30.6.2007)</td>
</tr>
<tr>
<td>EN 13445-5:2002/A4:2006</td>
<td>Note 3</td>
<td>Date Expired (30.6.2007)</td>
</tr>
</tbody>
</table>

Note 3: In case of amendments, the referenced standard is "EN CCCCYYYY", its previous amendments, if any, and the new quoted amendment. The superseded standard (column 3) therefore consists of "EN CCCCYYYY" and its previous amendments, if any, but without the new quoted amendment. On the date stated, the superseded standard ceases to give presumption of conformity with the essential requirements of the Directive.
EN 13445-5 (issue 1) 10.2.3.3 Standard hydrostatic test

For a vessel according to testing group 1, 2 or 3 the test pressure shall be not less than that determined by the following:

\[ P_t = 1.25 \, P_s \, \frac{f_a}{f_t} \quad \text{or} \quad P_t = 1.43 \, P_s \]

- \( P_t \) = test pressure
- \( P_s \) = maximum allowable pressure of the vessel
- \( f_a \) = nominal design stress for normal operating load cases at test temperature
- \( f_t \) = nominal design stress for normal operating load cases at the maximum allowable temperature

(Nominal design stress for group 1.1 steel = the smaller of values \( R_{p0.2} / 1.5 \) or \( R_m / 2.4 \))

The ratio \( \frac{f_a}{f_t} \) to be used shall be the greatest ratio of those permitted based on the material for the main pressure envelope elements.

The applied test pressure shall include the amount of any static head acting in service and in testing at the point under consideration (see Annex F). However, the static pressure caused by the content of the vessel during service and/or testing does not need to be taken into account if it does not increase the stress in the wall by more than 5%.

Special cases of EN 13445-5 (issue 1) Annex F (normative)

F.1 Vessels in vertical position during the pressure test and during operation when the operating medium has a greater density than the test medium

F.2 Vessels in horizontal position during the pressure test and in vertical position during operation

\[ P_{\text{test}}' = P_t + \Delta P_t \]

\( P_t \) is the "conventional" test pressure calculated by clause 10.2.3.3.1 and

\[ \Delta P_t = K (\rho_f \, g \, H_f + \frac{\rho_f}{\rho_t} \, g \, H_f + \frac{\rho_f}{\rho_t} \, g \, \frac{D_i}{2} ) \]

- \( \rho_t \) = density of test medium (kg/m³)
- \( H_f \) = static head of fluid, filling level during pressure test
- \( D_i \) = inside diameter of the vessel
- \( H_f \) = static head of fluid, maximum filling level during operation
- \( g \approx 9.81 \, \text{m/s}^2 \approx 10 \, \text{m/s}^2 \)
- \( K = 10^{-8} \) (corrections factor)
The pressure test requirements were completely revised by EN 13445-5 Amendment A2, published as issue 14 (2005-06)

For a single-compartment vessel, subjected to internal pressure, working below the creep range and designed according to testing group 1, 2 and 3, the test pressure, applied as internal pressure, shall be as specified in a) or b) and if necessary adjusted as specified in c).

a) can be applied if all the following conditions are met for the main pressure-bearing parts (shells, ends, tubesheets, tube bundles, main flanges) and bolting associated to main flanges

– the calculation pressure (considering the static head of fluid) does not differ from the maximum allowable pressure by more than 3 %
– the material design stress ratio $f_a / f_{ts}$ of all main pressure bearing parts or bolting does not differ by more than 3 %
– the sum of the deviations (absolute values) does not exceed 3 % in total
– the calculation temperature is not higher than the maximum allowable temperature

The test pressure shall not be less than that determined by the following:

$$P_t = 1.43 \ P_s \quad \text{or} \quad P_t = 1.25 \cdot \frac{P}{s} \cdot \frac{f_a}{f_{ts}}$$

- $P_t$ = test pressure measured at the highest point of the vessel in test position
- $P_s$ = maximum allowable pressure of the vessel
- $f_a$ = nominal design stress for normal operating load cases of the part at test temperature
- $f_{ts}$ = nominal design stress for normal operating load cases of the part at the maximum allowable temperature

EN 13445-5 A2 cont’d

b) If one or more of the conditions in a) can not be met, it is necessary to determine for each main pressure-bearing part and bolting associated to main flanges described in a) the test pressure $P_{tc}$ which shall not be less than that

$$P_{tc} = 1.25 \cdot \frac{P_c}{f_{tc}} \cdot \frac{f_{ac}}{f_{tc}} \quad \text{or} \quad P_{tc} = 1.43 \cdot P_c$$

- $P_{tc}$ = test pressure determined at the part
- $P_c$ = calculation pressure of the part
- $f_{ac}$ = nominal design stress for normal operating load cases of the part at test temperature
- $f_{tc}$ = nominal design stress for normal operating cases of the part at the calculation temperature

The test pressure of the vessel $P_t$ shall be the largest of all the values of $P_{tc}$ determined for each part.

The value of $P_t$ shall be applied at the highest point of the vessel for either horizontal or vertical test positions.
c) If in any main pressure-bearing part and bolting associated to main flanges the test pressure as calculated in b) exceeds the maximum permissible pressure for testing load cases one of the two following options shall be taken:

1) An increase of the thickness of the parts up to a value which makes the test pressure acceptable.

or

2) A reduction of the test pressure. If the test pressure is reduced, it shall not be reduced below the maximum permissible pressure of the weakest part for testing load cases.

With this second option, for parts for which the test pressure (measured at the highest point of the vessel) plus the result of hydrostatic pressure is less than the calculated test pressure for the part

the following tests are required for the whole vessel to give an equivalent level of safety

– Visual inspection with special emphasis on base material surface condition;
– The extent of NDT according to EN 13445-5 Table 6.6.2-1 shall be doubled but not greater than 100 %;
– Production tests in accordance with EN 13445-4 but always conducting transverse tensile tests for each welding procedure used for longitudinal governing welds.

It is extremely heavy to calculate the test pressure in accordance with EN 13445-5 / A2. In practice the calculation is done with a computer program.

This is because the "simple" method a) can in practice be applied only when

– all main parts of the pressure vessel is manufactured of same steel
– the specified fluid is gas

In practice the designer has to follow the method b)

The designer shall calculate for each main pressure-bearing component (shells, ends, tubesheets, tube bundles, main flanges and their bolting) the test pressure. The test pressure affecting a component depends of

– nominal design stress of the specified material
– calculation pressure (design pressure including hydrostatic pressure of the fluid) acting on the component

When specifying the test pressure of the complete pressure vessel the hydrostatic pressure of test fluid should be observed.

The test pressure to be applied at the highest point is largest value of the different test pressures of the components.

The designer shall also calculate the maximum permissible test pressure of the component.
Maximum allowable pressure 8,5 bar
Maximum design temperature +280 °C
Materials: P265GH EN 10028-2 and 1.4404 EN 10028-7

Datum line Vessel bottom

Maximum allowable pressure $P_s$ MPa 0,85
Fluid level from datum line at operation mm 2500
Fluid density kg/m3 1000
Pressure test reference elevation mm 7300
Density of test fluid kg/m3 1000
Component Top end Shell 1 Flanges Bolts Shell 2 Ends
Material 1.4404 1.4404 P265GH 8.8 P265GH 265GH
Thickness 11,2 10,0 100,0 20,0 20,0 20,0
Reference elevation from datum line 7200 4750 3900 3900 0 0
Design temperature C 280 280 280 280 280
Nominal design stress at test temperature $f_{ac}$ N/mm² 176,7 176,7 143,3 200,0 170,0 170,0
Nominal design stress at calculation temperature $f_{tc}$ N/mm² 124,8 124,8 96,8 160,0 114,7 114,7
Allowable stress at pressure test ( $R_{p0,2} / 1,05$ ) $f_{ac}$ N/mm² 247,6 247,6 257,1 610,0 242,9 242,9
Hydrostatic pressure during operation MPa 0,000 0,000 0,000 0,000 0,025 0,025
Calculation pressure $P_c$ MPa 0,850 0,850 0,850 0,850 0,875 0,875
Test pressure at the part under consideration $P_{tc}$ MPa 1,504 1,504 1,573 1,328 1,620 1,620
Effect of hydrostatic pressure of test fluid to the part MPa -0,001 -0,025 -0,033 -0,033 -0,072 -0,072
Test pressure at the highest point MPa 1,503 1,479 1,540 1,295 1,549 1,549
Required test pressure 15,49 bar
Maximum permissible pressure for test MPa 1,79 2,26 6,00 2,93 2,71 2,70

$$P_{tc} = 1,25 \cdot P_c \cdot \frac{f_{ac}}{f_{tc}} \quad \text{or} \quad P_{tc} = 1,43 \cdot P_c$$
24 m high hot-water storage tank of steel P265GH

700,000 L
PS = 0.9 bar (g)
Pc at bottom 0.33 MPa

Effective test pressure at bottom is 4.7 bar
(1.43 * 0.33 = 0.47) which means 2.3 bar (g) at top!

The standard proof test is the hydrostatic pressure test. If this is not practical it may be substituted by a pneumatic test.

- The test pressure to be used in pneumatic test in accordance with EN 13445-5 is the same as in hydrostatic pressure test!
  - The pneumatic test pressure is always at least 1.43 x maximum allowable pressure!

- Due to the hazards involved appropriate safety precautions shall be taken.
  - Testing shall be done in a special chamber capable to withstand the explosion or
  - all governing welded joints are required to be 100% RT or equivalent volumetric tested. All other welded joints shall be subjected to MT or PT, if they are not subjected to volumetric testing.

- After reaching and holding the test pressure for not less than 30 min the pressure shall be reduced to inspection pressure \( P_i \):

\[
P_i = P_s \cdot \frac{f}{f_t}
\]

and held during the inspection of the vessel.
Pressure vessels of testing group 4 (no NDT, only visual inspection) are subject to higher test pressure

**Pressure vessels manufactured of group 1.1 ferritic steel**

- if corrosion allowance $c < 1$ mm and measured peaking + $0.5 \cdot$ excess weld $\leq 0.5 \cdot c_{\text{min}}$

  \[ P_t = \sigma_{0.2} \cdot \frac{c}{e} \]

- if corrosion allowance $c \geq 1$ mm and measured peaking and excess weld are within certain limits

  \[ P_t = \sigma_{0.2} \cdot \frac{c_{\text{min}}}{e} \]

**Pressure vessels manufactured of group 8.1 austenitic steel**

- if measured peaking + $0.5 \cdot$ excess weld $\leq 0.5 \cdot c_{\text{min}}$

  \[ P_t = 1.85 \cdot P_s \cdot \frac{f_a}{f_t} \]

Some supplementary requirements of EN 13445-5 that may affect the testing of multi-compartment pressure vessels like heat exchangers or jacketed vessels.

- In the case of multi-compartment vessels each chamber, when designed as separate vessels, shall be tested independently with the appropriate standard test pressure without support from pressure in any adjoining chamber.

- If the common elements are designed for a larger differential pressure than the design pressure of the adjacent chambers, the test pressure shall subject the common elements to at least their design differential pressure as well as meeting the requirements for each independent chamber.

- For full or partial jacketed vessels, the inner vessel shall be subject to the maximum differential pressure caused by the vacuum in the adjacent chamber.

- Where it is reasonably practicable, single wall vessels subject to operation under vacuum conditions should be tested under vacuum or applied external pressure to simulate vacuum conditions. The pressure whether resulting from external pressure or from vacuum should be $1.25$ times the external design pressure, if possible, but in no case less than the external design pressure.
EN 13445-5 Amendment A3:2006, published as issue 20 (2006-05) sets additional requirements for pressure vessels with single run governing welds

The proof test pressure shall be increased by approximately 60%. The test pressure calculation factor shall be increased from 1,25 up to 2,1, depending on wall thickness and corrosion allowance.

- This means in many cases that the wall thickness of the pressure vessel shall be increased to withstand the pressure test.
- In addition to increased test pressure the weld shape deviations (peaking and excess weld) is also to be controlled.

As an alternative to higher test pressure there is an option to increase the extent of NDT

- The extent of NDT prescribed in EN 13445-5 Table 6.6.2-1 shall be multiplied by 2 but not less than 25% for longitudinal welds and 10% for circumferential welds.

EN 13445-5 / A3 restricts the range of welding procedure qualification of single run welding from $0,8 \cdot t$ to $t$, where $t$ is the actual nominal thickness of the test coupon.

d) For vessels with single run governing welds inspected according to 6.6.2.3.2 a), the proof test pressure shall be as follows:

$$ P_t = f_k \cdot P_s \cdot \frac{f_{a}}{f_{t}} \quad (10.2.3.3.1-5) $$

where

$P_t$ is the test pressure

$P_s$ is the maximum allowable pressure

$f_{a}$ is the nominal design stress for normal operating load cases at test temperature

$f_{t}$ is the nominal design stress for normal operating load cases at the maximum allowable temperature

The values of $f_k$ are given by Table 10.2.3.3.1-1.
Table 10.2.3.3.1-1 — Value of $f_k$

<table>
<thead>
<tr>
<th>Actual thickness of the shell $e$</th>
<th>$f_k$</th>
<th>Corrosion allowance $c$</th>
<th>maximum shape deviations $h$, peaking (measured after test) $e_w$, excess weld</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e \leq 4$ mm</td>
<td>2.1</td>
<td>$c \geq 1$ mm</td>
<td>$h + 0.5 \cdot e_w \leq 0.75 \cdot e_{min}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$c &lt; 1$ mm</td>
<td>$h + 0.5 \cdot e_{wa}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$e_w \leq 0.75 \cdot e_{wa}$</td>
</tr>
<tr>
<td>$4 &lt; e \leq 5$ mm</td>
<td>2.0</td>
<td>$c \geq 1$ mm</td>
<td>$h + 0.5 \cdot e_w \leq 0.5 \cdot e_{min}$</td>
</tr>
<tr>
<td></td>
<td>2.1</td>
<td>$c &lt; 1$ mm</td>
<td>$h + 0.5 \cdot e_{wa}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$e_w \leq 0.5 \cdot e_{wa}$</td>
</tr>
<tr>
<td>$5 &lt; e \leq 7$ mm</td>
<td>1.8</td>
<td>$c \geq 1$ mm</td>
<td>$h + 1 \cdot e_{wa}$</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>$c &lt; 1$ mm</td>
<td>$e_w &lt; 30%$ of allowed value given in Table 6.6.3.1</td>
</tr>
<tr>
<td>$7 &lt; e \leq 10$ mm</td>
<td>1.7</td>
<td>$c \geq 1$ mm</td>
<td>$h + 1 \cdot e_{wa}$</td>
</tr>
<tr>
<td></td>
<td>1.9</td>
<td>$c &lt; 1$ mm</td>
<td>$e_w &lt; 30%$ of allowed value given in Table 6.6.3.1</td>
</tr>
</tbody>
</table>

In Table 10.2.3.3.1-1:

- $e_{min}$ is the minimum possible fabrication thickness, as defined in EN 13445-3
- $h$ is the peaking after test, measured as defined in EN 13445-4
- $e_w$ is the excess weld, as illustrated by $h$ in number 1.5 of EN ISO 5817:2003

6.6.2.3.2 Single run one side governing welds

For single run governing welds made from one side, the thickness shall be limited to 10 mm. It is also noted that these vessels are limited to non cyclic duty i.e. 500 full pressure cycles. For volumetric NDT of single runs, one of the two options below shall be used:

a) NDT extent shall be as prescribed in Table 6.6.2-1 conditional upon a hydrotest at a higher test pressure performed as specified in paragraph 10.2.3.3.1, Table 10.2.3.3-1 with control of peaking and excess weld.

b) NDT extent prescribed in Table 6.6.2-1 shall be multiplied by 2 without exceeding 100 % but not less than 25 %. When there is a change which could influence the performance of the welding process (e.g., before changing the copper bar or the gas, after changing the wire or the powder and production test specimens, before changing the copper bar or gas and after changing wire) additional NDT shall be performed at the start of those seams.

For both a) and b), welding shall require qualification with welding procedure test, as requested in EN 13445-4, on the actual nominal thickness of the weld joint that is welded by the single run from one side. The range of qualification shall be restricted to $0.8 \cdot t$ to $t$, where $t$ is the actual nominal thickness of the test specimen.

For all thicknesses, X-Ray in the direction of the weld preparation shall be used.
4 CEN members (AT, BSI, FI and SE) objected the proposed Amendment A3. All considered the amendment to be too expensive to the industry. Their negative votes were not sufficient, all other CEN members approved the Amendment A3.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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</thead>
<tbody>
<tr>
<td>WB</td>
<td>Clause No</td>
<td>Paragraph No</td>
<td>Type</td>
<td>Justification</td>
<td>Proposed change</td>
<td>Securit Journal</td>
<td>Response of WD E90-0</td>
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<td>---</td>
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</tr>
<tr>
<td>2</td>
<td>BF 003</td>
<td>6.6.5</td>
<td>2</td>
<td>Vessel having single sided longitudinal welds are commonly used throughout Europe, for the storage of LPG. There are several million such vessels in service and several hundred thousand new vessels are constructed each year to the existing standards and codes. The service history and safety record of these vessels is excellent. The additional restrictions proposed in this amendment which appear to be completely without technical justification will, if adopted, add significantly to the cost of fabrication and be a disadvantage to industry contemplating the use of EN 13445 for such vessels.</td>
<td>Not accepted</td>
<td>Not accepted</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>AT 003</td>
<td>6.6.5</td>
<td>2</td>
<td>The restriction to 500000 pressure cycles is not acceptable - we do have rules for one-sided welds, and the restriction would eliminate quite conventional designs with one-sided circumferential welds almost totally!</td>
<td>This is in line with the basic design requirements of EN 13445. For fatigue loading we have to add additional requirements.</td>
<td>Not accepted</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>BS 030</td>
<td>6.6.3</td>
<td>1</td>
<td>UK has concerns with regard to the inclusion of 0.8 i in the penultimate paragraph, why not 1.1 as in the welding standards? In addition this paragraph is not appropriate to this standard</td>
<td>Remove paragraph</td>
<td>Not accepted</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>SE 013</td>
<td>6.9.3.1</td>
<td>2</td>
<td>The restriction of thickness to EN 288-3 should be in part 4.</td>
<td>Will be considered for a next revision</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The current EN 13445-5 requirements for the determination of test pressure has caused a lot of debate.

In some cases the required test pressure might be so high that some parts must be strengthened to withstand the test pressure. This is because of the requirement that the test pressure of the vessel $P_t$ shall be the largest of all the values of $P_{tc}$ determined for each part.

A new amendment A10 to EN 13445-5 is under preparation by CEN / TC 54 / WG E, the latest draft EN 13445-5:2002 / prA10:2007.6 has been sent for public enquiry.

Main difference to current EN 13445-5 is in the case of pressure vessels constructed of different materials the calculated test pressure is based on the smallest ratio of nominal design stresses $\frac{f_a}{f_{Ts}}$ and the test pressure calculation is affected only by maximum allowable pressure, the hydrostatic pressure of fluid will be neglected.

If the draft EN 13445-5:2002 / prA10:2007.6 will be approved the requirement for test pressure will be almost like the original EN 13445-5 Issue 1!

\[ P_t = 1.25 \cdot \frac{P_s \cdot f_a}{f_{Ts}} \quad (10.2.3.3.1-1) \]

or

\[ P_t = 1.43 \cdot P_s \quad (10.2.3.3.1-2) \]

whichever is the greater.

where:

- $P_t$ is the test pressure measured at the highest point of the chamber of the vessel in test position;
- $P_s$ is the maximum allowable pressure of the vessel;
- $f_a$ is the nominal design stress for normal operating load cases of the part under consideration at test temperature;
- $f_{Ts}$ is the nominal design stress for normal operating load cases of the part under consideration at maximum allowable temperature $T_s$;

$P_t$, $P_s$, $f_a$ and $f_{Ts}$ shall have consistent units.
The ratio \( \frac{f_a}{f_{ts}} \) (depending on the different materials used for a vessel) shall be at least the smallest ratio of the materials of the main pressure bearing parts (e.g. shells, ends, tubesheets of heat exchangers, tube bundles, main flanges and bolting associated to main flanges).

If the bolting associated to main flanges is overstressed due to the test pressure, the test pressure may be reduced until the bolt stresses are acceptable.

Main pressure bearing parts do not include pressure rated standard flanges and bolting designed without calculation according to the rules of paragraph 11.4.2 of EN 13445-3.

NOTE The rules of paragraph 11.4.2 of EN 13445-3 deal with the use of standard flanges without calculation.