Annex B
(normative)

Determination of pressure factors and wall thickness

B.1 General

Annex B defines pressure factors for fittings of type A and wall thickness requirements of fittings of type B. This is done by laying down appropriate calculation procedures in detail.

The pressure factor of a fitting of type A gives the percentage of internal pressure which may, in general, be applied to the fitting relative to the pressure which may be applied to a straight pipe with the same dimensions (diameter, wall thickness, wall thickness tolerance) and material. The wall thickness tolerance of this pipe is assumed to be the same as the wall thickness tolerances at the welding ends of the fitting.

The wall thicknesses of fittings type B are laid down so that the fittings will, in general, withstand the same internal pressure as a straight pipe with the same dimensions (diameter, wall thickness, wall thickness tolerance) and material. Wall thickness tolerance of this corresponding straight pipe is assumed to be the same as the wall thickness tolerances at the welding ends of the fitting.

NOTE The calculation procedures are based on the design rules laid down in EN 13480-3:2002. Most of the formulas may be applied in case of time-independent and time-dependent loads. Where the formulas are valid only for time-independent loads appropriate notes are made in Annex B.

B.2 Symbols and units

For the purposes of Annex B, C and D, the symbols given in Table B.1 shall apply in addition to those given in Clause 4. Dimensions are in millimetres.

Table B.1 — Additional symbols for the purposes of Annexes B, C and D

Symbol	Description
A_f	Stress loaded cross sectional area (calculation of tees)
A_{fs}, A_{fsc}, A_{fbc}, A_{fb}	Partial Areas of A_f (calculation of tees)
A_p	Pressure loaded area (calculation of tees)
A_{pbc}, A_{psc}	Areas used in the determination of A_p (calculation of tees)
c_0	Corrosion or erosion allowance
D_b	Outside diameter at the body of the branch of tees type B
D_s	Outside diameter at the body of the run of tees type B
L_2	Length at the major end of reducers
L'_2	Length of cylindrical part at the major end of reducers
$L_{2,min}$	Minimum length at the major end of reducers
$L'_{2,min}$	Minimum length of cylindrical part at the major end of reducers
L_4	Length at the minor end of reducers
$L_{4,min}$	Minimum length at the minor end of reducers
l_b	Reinforcing length of branch (calculation of tees)
l'_b	Modified reinforcing length of branch (calculation of tees)
l_s	Reinforcing length of run (calculation of tees)

Symbol	Description
l'_s	Modified reinforcing length of run (calculation of tees)
r	Bending radius of elbows and return bends relating to the internal diameter
r_c	Crotch radius of tees
$T_{1,min}$	Minimum wall thickness at the minor welding end of reducers and at the welding end of the branch of reducing tees (D_1) Minimum wall thickness of the branch of reducing tees type A Minimum wall thickness of the cylindrical part at the minor end of reducers type A
$T_{1,X}$	Wall thickness of a straight pipe with the same resistance to pressure as a fitting type A (equivalent wall thickness) with the diameter D_1 (minor end of a reducer)
T_2	Wall thickness of the cylindrical part of reducers type B at their major end
$T_{2,min}$	Minimum wall thickness of the cylindrical part of reducers type B at their major end
$T'_{2,min}$	Minimum wall thickness of a cylindrical part with modified length of reducers type B at their major end
T_3	Wall thickness of the conical part of reducers type B
$T_{3,min}$	Minimum wall thickness of the conical part of reducers type B
T_4	Wall thickness of the cylindrical part of reducers type B at their minor end
$T_{4,min}$	Minimum wall thickness of the cylindrical part of reducers type B at their minor end
$T'_{4,min}$	Minimum wall thickness of a cylindrical part with modified length of reducers type B at their minor end
T_b	Wall thickness on the branch of tees type B
$T_{b,min}$	Minimum wall thickness on the branch of tees type B
$T_{bc,min}$	Intermediate result (calculation of tees)
T_c	Wall thickness of caps type B
$T_{c,min}$	Minimum wall thickness of caps type B Minimum wall thickness on the crotch zone of tees
$T_{co,min}$	Intermediate result (calculation of reducers type B)
T_{ext}	Wall thickness on the extrados of elbows type B
$T_{ext,min}$	Minimum wall thickness on the extrados of elbows type B
T_{int}	Wall thickness on the intrados of elbows type B
$T_{int,min}$	Minimum wall thickness on the intrados of elbows type B
$T_{j,min}$	Intermediate result (calculation of reducers type B)
$T_{kn\ y,min}$	Intermediate result (calculation of caps type B)
$T_{kn\ b,min}$	Intermediate result (calculation of caps type B)
T_{min}	Minimum wall thickness at the welding ends of elbows, return bends, caps and equal tees, at the welding ends of the run of reducing tees or at the major welding end of reducers Minimum wall thickness at the body of elbows, return bends, equal tees and caps of type A Minimum wall thickness of the run of reducing tees type A Minimum wall thickness of the cylindrical part at the major end of reducers type A and of the conical part of reducers type A
T_s	Wall thickness at the run of tees type B
$T_{s,min}$	Minimum wall thickness at the run of tees type B Intermediate result (calculation of caps type B)
$T_{sc,min}$	Intermediate result (calculation of tees)
T_X	Wall thickness of a straight pipe with the same pressure resistance as a fitting of type A (equivalent wall thickness)
$T_{X,23}$, $T_{X,3}$, $T_{X,34}$, $T_{X,4}$, T'_{L2}, T_{L2}, T'_{L4}, T_{L4},	Intermediate results (calculation of reducers type A)

Symbol	Description
$T_{X,s}$, $T_{X,kn\ y}$, $T_{X,kn\ b}$	Intermediate results (calculation of caps type A)
$T_{\alpha,min}$	Minimum wall thickness at the body of elbows type B (between intrados and the crown)
X	Pressure factor: ratio of the pressure a fitting of type A will resist to the pressure a straight pipe (with same dimensions and material) will resist
α	Semi angle of reducer Angle at the perimeter of elbows (for the evaluation of the wall thickness at the body of the elbow)
α_b, α_s	Angle (intermediate result in the calculation of tees)
β, $\beta_{0.06}$, $\beta_{0.1}$, $\beta_{0.2}$, N, W, Y, Z	Factors (calculation of caps)
β, β_H, s, τ	Factors (calculation of reducers)

B.3 Minimal and nominal wall thickness

The design rules given in EN 13480-3:2002 are based on minimal required wall thicknesses. Therefore, in a first step, these minimal wall thicknesses have to be derived from the nominal wall thickness of the fitting. Taking into account the negative tolerances given in Table 9 and the corrosion or erosion allowance c_0 the minimal wall thickness is calculated:

$$T_{\min} = \begin{cases} T \cdot (100 - 12.5)/100 - c_0 & \mathit{if}\, D \leq 610\ mm \\ T - 0.35\ mm - c_0 & \mathit{if}\, D > 610\ mm\ \ and\ T \leq 10\ mm \\ T - 0.5\ mm - c_0 & \mathit{if}\, D > 610\ mm\ \ and\ T > 10\ mm \end{cases} \tag{B.1}$$

To obtain a wall thickness including wall thickness tolerances and corrosion or erosion allowance from a minimal wall thickness the following equation is used:

$$T = \begin{cases} (T_{\min} + c_0) \cdot 100/(100 - 12.5) & \mathit{if}\, D \leq 610\ mm \\ T_{\min} + c_0 + 0.35\ mm & \mathit{if}\, D > 610\ mm\ \ and\ T_{\min} + c_0 \leq 9{,}65\ mm \\ T_{\min} + c_0 + 0.5\ mm & \mathit{if}\, D > 610\ mm\ \ and\ T_{\min} + c_0 > 9{,}65\ mm \end{cases} \tag{B.2}$$

If other tolerances are specified for the fitting, these values have to be used in above formulas.

For fittings of type B the corrosion or erosion allowance c_0 shall be 0.

NOTE In general, $c_0 = 0$ has the consequence that elbows, tees and reducers will withstand at least the same pressure as the corresponding straight pipe for all corrosion or erosion allowances.

B.4 Pressure factors of fittings of type A

B.4.1 General

The formulas are based on the outside diameters of the fittings. They may be used for fittings designated by their internal diameter by setting $D = ID + 2\,T$.

B.4.2 Pressure factor

In general, fittings of type A will not withstand the same internal pressure as a straight pipe with the same dimensions (diameter, wall thickness, wall thickness tolerance) and material. To support the designer of a piping system a pressure factor X is calculated. This pressure factor X giving the ratio of the pressure the fitting will resist to the pressure the pipe will resist:

$$X = \frac{pressure\ resis\tan ce\ of\ \ fitting}{pressure\ resis\tan ce\ of\ \ pipe} \cdot 100\% \tag{B.3}$$

In many cases the design formulas for fittings are based on the wall thickness of a straight pipe. Therefore, in a first step, the wall thickness T_X of a pipe with the same outside diameter, which will resist to the same pressure as the given fitting, (equivalent wall thickness) will be determined. The pressure factor X is calculated afterwards:

$$X = \frac{\frac{T_X}{D}}{\frac{T_{\min}}{D}} \cdot \frac{1 - \frac{T_{\min}}{D}}{1 - \frac{T_X}{D}} \cdot 100\% \tag{B.4}$$

NOTE Formula (B.4) is derived from (6.1-1) from EN 13480-3:2002.

For fittings with two different ends (reducers and reducing tees) the pressure factor shall be calculated:

$$X = \frac{\frac{T_X}{D}}{\min\left(\frac{T_{\min}}{D}, \frac{T_{1,\min}}{D_1}\right)} \cdot \frac{1 - \min\left(\frac{T_{\min}}{D}, \frac{T_{1,\min}}{D_1}\right)}{1 - \frac{T_X}{D}} \cdot 100\% \tag{B.5}$$

B.4.3 Elbows

For elbows, the equivalent wall thickness is given by:

$$T_X = \frac{4 \cdot R - 2 \cdot D + 2 \cdot T_{\min}}{4 \cdot R - D} \cdot T_{\min} \tag{B.6}$$

NOTE Formula (B.6) is derived from (B.4.1-11) from EN 13480-3:2002 by setting $B = e_i/e$ and solving the equation for e.

Example:

Pressure factor of an elbow model 2D - 711 x 7.1 (R = 711 mm), corrosion or erosion allowance 1 mm:

(B.1): $T_{\min}$ = 7,1 mm – 0,35 mm – 1 mm= 5,75 mm

(B.6): T_X = 3.864 mm

(B.4): X = 67,0 %

B.4.4 Tees

The calculation procedure for tees is based on the design rules in EN 13480-3:2002. It includes the determination of the stress loaded cross sectional area A_f and the pressure loaded cross sectional area A_p, which are shown in Figure B.1.

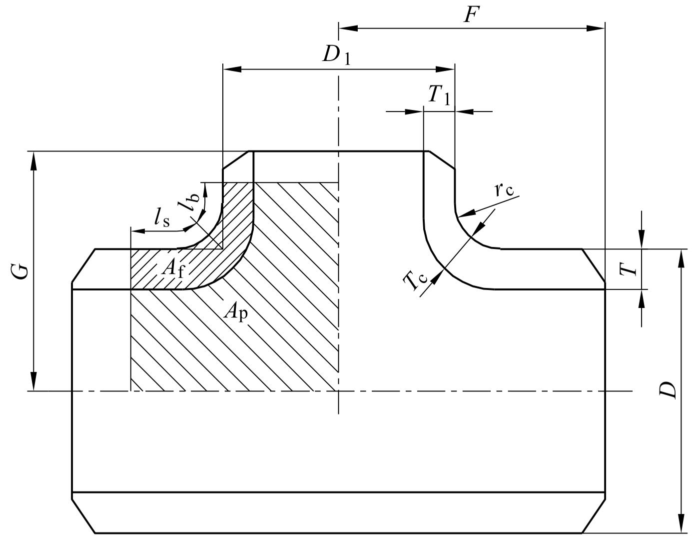

Figure B.1 — Tee type A

With these areas A_p and A_f the wall thickness of a pipe with the same resistance to internal pressure as the tee is given by:

$$T_X = \frac{D}{2 \cdot \left(\frac{A_p}{A_f} + 1 \right)} \tag{B.7}$$

The reinforcing lengths are calculated:

$$l_s = \min\left(\sqrt{(D - T_{\min}) \cdot T_{\min}} \,,\, F - \frac{D_1}{2} - \left(1 - \frac{\pi}{4}\right) \cdot r_c \right) \tag{B.8}$$

$$l_b = \min\left(\sqrt{(D_1 - T_{1,\min}) \cdot T_{1,\min}} \,,\, G - \frac{D}{2} - \left(1 - \frac{\pi}{4}\right) \cdot r_c \right) \tag{B.9}$$

At the transition of run and branch (crotch zone) the inside and outside surfaces shall merge smoothly.

NOTE 1 Formula (B.7) is only applicable if $T_{1,\min}$ is less equal $T_{\min}$.

NOTE 2 Formula (B.7) is derived from (8.4.3-3) and (6.1-1) from EN 13480-3:2002,
Formulas (B.8) and (B.9) are based on (8.4.1-2) and (8.4.3-1) from EN 13480-3:2002.
The requirement $T_{1,\min} \leq T_{\min}$ is more restrictive than the stipulation in EN 13480-3:2002, Figure 8.3.1-1.

NOTE 3 In EN 13480-3:2002 the design is limited to $D_1 - 2 \cdot T_{1,\min} \leq D - 2 \cdot T_{\min}$ for austenitic steels and to $D_1 - 2 \cdot T_{1,\min} \leq 0{,}8\ (D - 2 \cdot T_{\min})$ for materials others than austenitic steels. For applications within the creep range it is limited to $D_1 - 2 \cdot T_{1,\min} \leq 0{,}7\ (D - 2 \cdot T_{\min})$ and the pressure factor should be multiplied by 0,9.

Example:

Pressure factor of a reducing tee 813 x 8 – 508 x 6.3,
c_0 = 0 mm, F = 597 mm, G = 533 mm , r_c = 95 mm and $T_{c,min} = (T_{s,min} + T_{b,min})$ / 2:

(B.1): T_{min} = 8 mm – 0,35 mm – 0 mm = 7,650 mm
$T_{1,min}$ = 6,3 mm (100 – 12,5) / 100 – 0 mm = 5,513 mm
$T_{c,min}$ = (7,65 mm + 5,513 mm) / 2 = 6,581 mm

(B.8): l_s = 78,49 mm

(B.9): l_b = 52,63 mm

For the calculation of areas A_f and A_p see Figure B.2.

$$\alpha_s = 45° \cdot \max\left(1 - \frac{l_s}{\frac{\pi}{4} \cdot r_c}, 0\right) = 0.00°$$

$$\alpha_b = 45° \cdot \max\left(1 - \frac{l_b}{\frac{\pi}{4} \cdot r_c}, 0\right) = 13.26°$$

$$l'_s = r_c - r_c \cdot \sin(\alpha_s) + \max\left(l_s - r_c \cdot \frac{\pi}{4}, 0\right) = 98.88\ mm$$

$$l'_b = r_c - r_c \cdot \sin(\alpha_s) + \max\left(l_b - r_c \cdot \frac{\pi}{4}, 0\right) = 73.21\ mm$$

$$T_{sc,\min} = \frac{45° - \alpha_s}{45°} \cdot T_{\min} + \frac{\alpha_s}{45°} \cdot T_{c,\min} = 7.650\ mm$$

$$T_{bc,\min} = \frac{45° - \alpha_b}{45°} \cdot T_{1,\min} + \frac{\alpha_b}{45°} \cdot T_{c,\min} = 5.827\ mm$$

$$A_{fs} = \max(l'_s - r_c, 0) \cdot T_{\min} = 29.7\ mm^2$$

$$A_{fsc} = \left(\left(r_c + \frac{T_{sc,\min} + T_{c,\min}}{2}\right)^2 - r_c^2\right) \cdot \pi \cdot \frac{45° - \alpha_s}{360°} + T_{sc,\min}^2 \cdot \frac{\tan(\alpha_s)}{2} = 550.8\ mm^2$$

$$A_{fbc} = \left(\left(r_c + \frac{T_{bc,\min} + T_{c,\min}}{2}\right)^2 - r_c^2\right) \cdot \pi \cdot \frac{45° - \alpha_b}{360°} + T_{bc,\min}^2 \cdot \frac{\tan(\alpha_b)}{2} = 341.2\ mm^2$$

$$A_{fb} = \max(l'_b - r_c, 0) \cdot T_{1,\min} = 0.0\ mm^2$$

$$A_f = A_{fs} + A_{fsc} + A_{Fbc} + A_{fb} = 921.7\ mm^2$$

$$A_{psc} = r_c^2 \cdot \left(\frac{1}{2} \cdot (1 - \sin(\alpha_s))^2 - \pi \cdot \frac{45° - \alpha_s}{360°} + \frac{1}{2} \cdot \sin(\alpha_s) \cdot (\cos(\alpha_s) - \sin(\alpha_s))\right) = 968\ mm^2$$

$$A_{pbc} = r_c^2 \cdot \left(\frac{1}{2} \cdot (1 - \sin(\alpha_b))^2 - \pi \cdot \frac{45° - \alpha_b}{360°} + \frac{1}{2} \cdot \sin(\alpha_b) \cdot (\cos(\alpha_b) - \sin(\alpha_b))\right) = 950\ mm^2$$

$$A_p = \left(\frac{D1}{2} + l'_s\right) \cdot \left(\frac{D}{2} + l'_b\right) - l'_s \cdot l'_b + A_{psc} + A_{psb} - A_f = 163038\ \mathrm{mm}^2$$

$$\frac{A_p}{A_f} = 176.89$$

(B.7): T_X = 2,285 mm

(B.5): X = 29,7 %

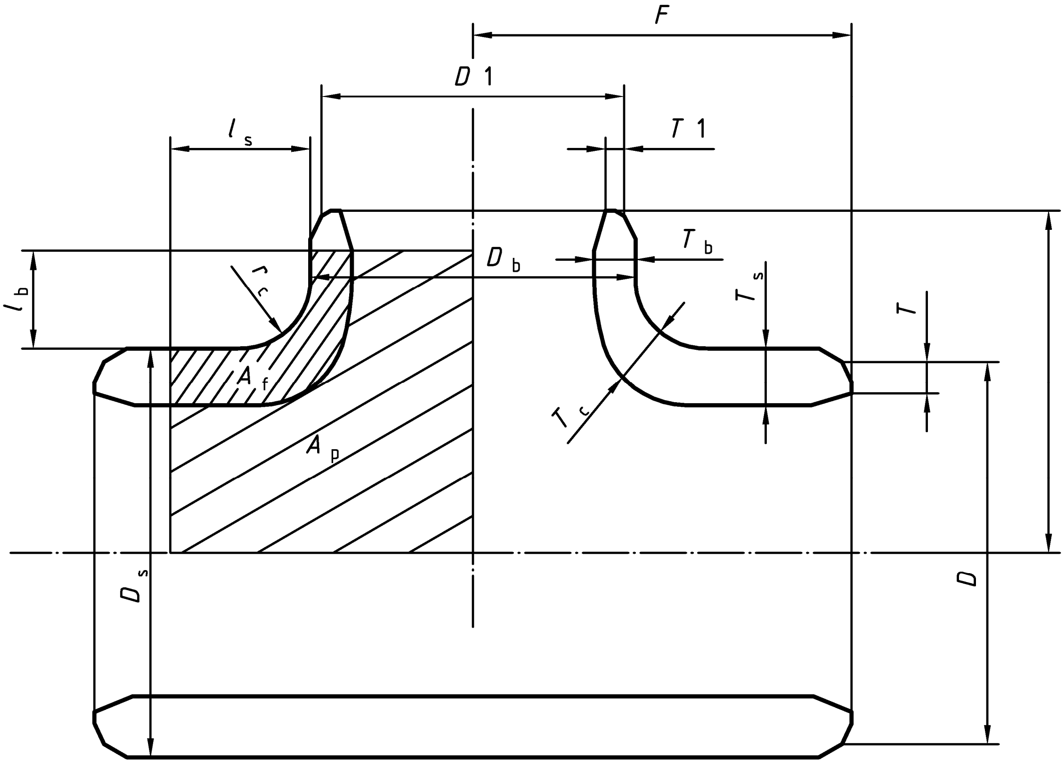

Figure B.2 — Additional dimensions and areas used in the calculation A_p and A_f of a tee

B.4.5 Reducers

For the determination of the pressure resistance of reducers several aspects have to be taken into consideration. The calculations are based on the following preconditions:

— The wall thickness in the conical section is at least the wall thickness at the major end of the reducer;

— The reducer has cylindrical sections on both ends of the reducer. In some cases minimal lengths of these sections are required;

— At the transition of cylindrical sections and conical sections the inside and outside surfaces shall merge smoothly;

— The transition between the cylindrical sections and the conical section at the major end may be curved. In this case the distance between the knuckle and the end of the reducer shall be at least:

$$L'_{2,\min} = 0.5 \cdot \sqrt{(D - T_{L2}) \cdot T_{L2}} \tag{B.10}$$

— The transition between the cylindrical sections and the conical section at the minor end may be curved too. The wall thickness of the knuckle shall be the same as of the conical section.

Figure B.3 shows wall thicknesses, minimal lengths at the ends and the semi angle for both concentric and eccentric reducers.

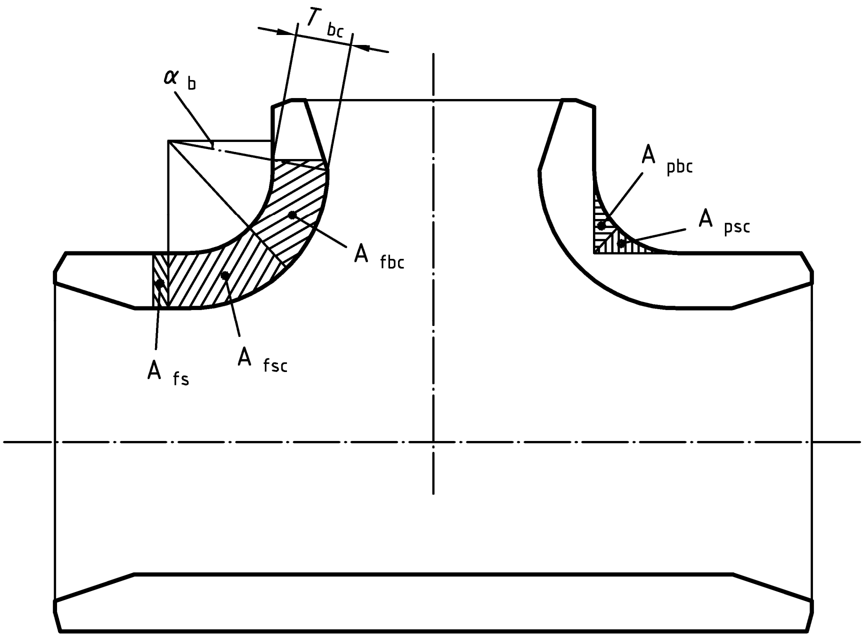

Figure B.3 — Concentric and eccentric reducer type A

The design of a reducer comprises the determination of the wall thickness at the cylindrical sections, the wall thickness at the conical section and the wall thicknesses at the transitions between cylindrical and conical sections. Therefore, first the equivalent wall thickness at different sections of the reducer have to be calculated. In the next step the overall equivalent wall thickness of the reducer is determined.

$$T_{X,23} = T_{\min} \cdot \frac{D}{\beta \cdot (D - T_{\min}) + T_{\min}} \tag{B.11}$$

$$T_{X,3} = T_{\min} \cdot \cos(\alpha) \cdot \frac{D}{D - 2 \cdot T_{\min} - \sqrt{\frac{(D - T_{\min}) \cdot T_{\min}}{\cos(\alpha)}} \cdot \sin(\alpha) + T_{\min} \cdot \cos(\alpha)} \tag{B.12}$$

$$T_{X,34} = T_{\min} \cdot \frac{D}{\beta_H \cdot (D_1 - T_{1,\min}) \cdot \frac{T_{\min}}{T_{1,\min}} + T_{\min}} \tag{B.13}$$

$$T_{X,4} = T_{1,\min} \cdot \frac{D}{D_1} \tag{B.14}$$

$$T_X = \min(T_{X,23},\ T_{X,3},\ T_{X,34},\ T_{X,4}) \tag{B.15}$$

$$T_{1,X} = T_X \cdot \frac{D_1}{D} \tag{B.16}$$

with the factors β and β_H:

$$\beta = \max\left(\frac{1}{3} \cdot \sqrt{\frac{D - T_{\min}}{T_{\min}}} \cdot \frac{\tan(\alpha)}{1 + \frac{1}{\sqrt{\cos(\alpha)}}} - 0.15,\ 1 \right) \tag{B.17}$$

$$s = \frac{T_{\min}}{T_{1,\min}} \tag{B.18}$$

$$\tau = \begin{cases} s \cdot \sqrt{\dfrac{s}{\cos(\alpha)}} + \sqrt{\dfrac{1+s^2}{2}} & if\ s < 1 \\ 1 + \sqrt{s \cdot \dfrac{1+s^2}{2 \cdot \cos(\alpha)}} & if\ s \geq 1 \end{cases} \tag{B.19}$$

$$\beta_H = 0.4 \cdot \sqrt{\frac{D_1 - T_{1,\min}}{T_{1,\min}}} \cdot \frac{\tan(\alpha)}{\tau} + 0.5 \tag{B.20}$$

Afterwards, the minimal lengths at the ends have to be calculated. In a first step, the wall thicknesses T_{L2} and T_{L4} are determined. These wall thicknesses are required at the cylindrical sections so that the reducer is able to resist the pressure expressed by the pressure factor X. The following equations have to be solved by iteration:

$$T'_{L2} = \beta \cdot T_X \cdot \frac{D}{D + (\beta - 1) \cdot T_X} \tag{B.21}$$

$$T_{L2} = \max(T_X,\ T'_{L2}) \tag{B.22}$$

$$T'_{L4} = \beta_H \cdot T_{1,X} \cdot \frac{D}{D + (\beta_H - 1) \cdot T_X} \tag{B.23}$$

$$T_{L4} = \max(T_{1,X},\ T'_{L4}) \tag{B.24}$$

with the factors β and β_H:

$$\beta = \frac{1}{3} \cdot \sqrt{\frac{D - T'_{L2}}{T'_{L2}}} \cdot \frac{\tan(\alpha)}{1 + \dfrac{1}{\sqrt{\cos(\alpha)}}} - 0.15 \tag{B.25}$$

$$s = \frac{T_{\min}}{T'_{L4}} \tag{B.26}$$

$$\tau = \begin{cases} s \cdot \sqrt{\dfrac{s}{\cos(\alpha)}} + \sqrt{\dfrac{1+s^2}{2}} & if\ s < 1 \\ 1 + \sqrt{s \cdot \dfrac{1+s^2}{2 \cdot \cos(\alpha)}} & if\ s \geq 1 \end{cases} \tag{B.27}$$

$$\beta_H = 0.4 \cdot \sqrt{\frac{D_1 - T'_{L4}}{T'_{L4}}} \cdot \frac{\tan(\alpha)}{\tau} + 0.5 \tag{B.28}$$

With these wall thicknesses the minimal lengths are calculated:

$$L_{2,\min} = \frac{T_{L2} - T_X}{T_{\min} - T_X} \cdot 1.4 \cdot \sqrt{(D - T_{L2}) \cdot T_{L2}} \tag{B.29}$$

$$L_{4,\min} = \frac{T_{L4} - T_{1,X}}{T_{1,\min} - T_{1,X}} \cdot \sqrt{(D_1 - T_{L4}) \cdot T_{L4}} \tag{B.30}$$

The length $L_{2,\min}$ is applicable only if T_X is less than $T_{\min}$, $L_{4,\min}$ is applicable if $T_{1,X}$ is less than $T_{1,\min}$. If the reducer is located between pipes with minimal wall thicknesses larger than T_{L2} and T_{L4}, respectively, the minimal lengths do not apply, too.

The calculation procedure described may be used for straight reducers provided the circumflex welds at the ends of the reducers shall be subject to 100% non-destructive examination, either by radiography or ultrasonic techniques, and the reducer is located between pipes with minimal wall thicknesses of at least T_{L2} and T_{L4}, respectively. If no non-destructive examination of the welds is done, the pressure factor shall be multiplied by 0.7.

NOTE 1 Formula (B.12) to (B.28) are applicable only for semi angle α less equal 75° and ratios of $T_{\min} \cos(\alpha)$ to D not smaller than 0,001.

NOTE 2 The calculation of reducers is based on the following sections/equations in EN 13480-3:2002:
Formula (B.10) is based on the stipulations in 6.4.7.2,
Formula (B.11) takes into account 6.4.6.3 a) and 6.4.6.3 g),
Formula (B.12) takes into account 6.4.6.3 b) and 6.4.6.3e),
Formula (B.13) takes into account 6.4.8.3,
Formula (B.14) takes into account the pressure resistance of the cylindrical part at the minor end.
Formulas (B.17) and (B.25) are based on (6.4.6-1),
Formulas (B.18) and (B.26) are given as (6.4.8-1),
Formulas (B.19) and (B.27) are based on (6.4.8-2) and (6.4.8-3),
Formulas (B.20) and (B.28) are given as (6.4.8-4),
Formula (B.21) is derived from (6.4.6-2) and (6.1-1),
Formula (B.23) is derived from (6.4.8-6) and (6.1-1).

The calculation of the minimal length at the ends of the reducers (B.29) and (B.30) takes into account that the wall thickness near the junction may be increased and the wall thickness further away may be reduced provided that the cross-sectional area remains constant (see last paragraph of 6.4.6.2 and last paragraph of 6.4.8.2 of in EN 13480-3:2002) and that the reducer will be located between pipes with minimal wall thicknesses of at least T_X and $T_{1,X}$.

No additional calculation of the wall thickness of the knuckle at the major end is required. The formulas in EN 13480-3:2002 (6.4.7-1) to (6.4.7-4) give wall thicknesses which are not larger than for junctions without a knuckle.

The rules for a knuckle at the minor end differs from the stipulations in EN 13480-3:2002.

The stipulations for straight reducers are based on EN 13480-3:2002 6.4.6.1 2).

Example:

Pressure factor of a concentric reducer 323,9 x 7,1 – 168,3 x 4,5,
c_0 = 0 mm, semi angle α = 35°:

Table A.5: L = 203 mm.

(B.1): $T_{\min}$ = 7,1 mm (100 – 12,5) / 100 – 0 mm = 6,213 mm
$T_{1,\min}$ = 4,5 mm (100 – 12,5) / 100 – 0 mm = 3,938 mm

(B.17): β = 1,000

(B.18): s = 1,578

(B.19): τ = 2,833

(B.20): β_H = 1,139

(B.11): $T_{X,23}$ = 6,213 mm

(B.12): $T_{X,3}$ = 5,715 mm

(B.13): $T_{X,34}$ = 6,674 mm

(B.14): $T_{X,4}$ = 7,578 mm

(B.15): T_X = 5,715 mm

(B.16): $T_{1,X}$ = 2,970 mm

(B.5): X = 91,9 %

The calculation of the minimal lengths at the ends of the cylinders:

Result of solving (B.21) and (B.25) by iteration: T_{L2} = 4,499 mm, β = 0,784

Result of solving (B.23) with (B.26), (B.27) and (B.28) by iteration: T_{L4} = 3,261 mm, s = 1,905, τ = 3,320, β_H = 1,100

(B.22): T_{L2} = 5,715 mm

(B.24): T_{L4} = 3,261 mm

(B.29): $L_{2,\min}$ = 0,00 mm (no specific length required)

(B.10): $L_{2,\min}$ = 21,32 mm

(B.30): $L_{4,\min}$ = 6,99 mm

B.4.6 Caps

The design of a cap comprises the determination of the wall thickness of the spherical end, the wall thickness of the knuckle and the wall thickness of the cylindrical part. Therefore, first the equivalent wall thickness at different sections of the cap has to be calculated. In the next step the overall equivalent wall thickness of the cap is determined:

$$T_{X,s} = T_{\min} \cdot \frac{D}{R1 + 1.5 \cdot T_{\min}} \tag{B.31}$$

$$T_{X,kn\,y} = T_{\min} \cdot \frac{D}{2 \cdot \beta \cdot (0.75 \cdot R1 + 0.2 \cdot (D - 2 \cdot T_{\min})) + T_{\min}} \tag{B.32}$$

$$T_{X,kn\,b} = \frac{D}{\frac{2}{111} \cdot \left(\frac{0.75 \cdot R1 + 0.2 \cdot (D - 2 \cdot T_{\min})}{T_{\min}} \right)^{1.5} \cdot \left(\frac{D - 2 \cdot T_{\min}}{r} \right)^{0.825} + 1} \tag{B.33}$$

$$T_X = \min\left(T_{X,s},\ T_{X,kn\,y}\ \ T_{X,kn\,b},\ T_{\min}\right) \tag{B.34}$$

The factors β is calculated:

$$Y = \min\left(\frac{T_{\min}}{R1},\ 0.04 \right) \tag{B.35}$$

$$Z = \log\left(\frac{1}{Y} \right) \tag{B.36}$$

$$W = \frac{r}{D - 2 \cdot T_{\min}} \tag{B.37}$$

$$N = 1.006 - \frac{1}{6.2 + (90 \cdot Y)^4} \tag{B.38}$$

$$\beta_{0.06} = \left(-0.3635 \cdot Z^3 + 2.2124 \cdot Z^2 - 3.2937 \cdot Z + 1.8873\right) \cdot N \tag{B.39}$$

$$\beta_{0.1} = \left(-0.1833 \cdot Z^3 + 1.0383 \cdot Z^2 - 1.2943 \cdot Z + 0.837\right) \cdot N \tag{B.40}$$

$$\beta_{0.2} = 0.5 \tag{B.41}$$

$$\beta = \begin{cases} 25 \cdot \left((0.1 - W) \cdot \beta_{0.06} + (W - 0.06) \cdot \beta_{0.1}\right) & \text{if } 0.06 \le W \le 0.1 \\ 10 \cdot \left((0.2 - W) \cdot \beta_{0.1} + (W - 0.1) \cdot \beta_{0.2}\right) & \text{if } 0.1 < W \le 0.2 \end{cases} \tag{B.42}$$

NOTE 1 Formulas (B.31) to (B.42) are applicable provided that the following conditions are simultaneously fulfilled: $r \ge 0{,}06\ (D - 2\ T_{\min})$