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6 EQU
Form for equations

Equation form

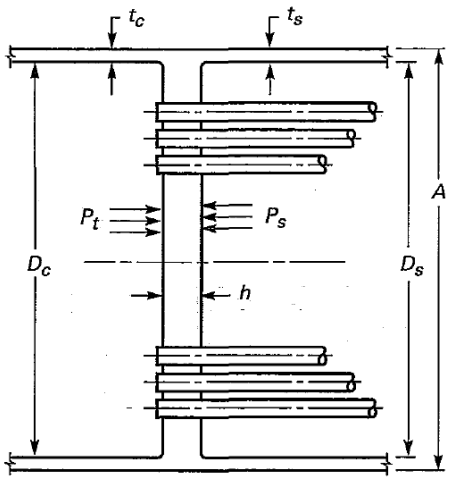
Comment

Comparison ASME UHX-E4.18.1-4 and LV with equations and conversion factors.
Summary in tables E4.18.1...4
All differences are less than 1%.

Equations		**Value**
Conversion factors	MPa2psi = 145: N2lb = 0.2248	**0.2248**
'Results step 1		**0**
LV my*	my_= #88(1)	**0.349**
ASME	my_A = 0.349	**0.349**
LV	MTS = N2lb*#120(1)	**-160.4**
ASME	MTSa = -160	**-160**
LV ny*	ny_= #100(1)	**0.2539**
ASME	ny_A = 0.254	**0.254**
LV E*	E_ = MPa2psi*#98(1)	**1.152e+7**
ASME	E_a = 11.5E6	**1.15e+7**
'Moments, step 6 and 7		**0**
LV	M_ = N2lb*#134(1)	**-49.62**
ASME M*	M_A = -49.4	**-49.4**
LV	Mp = N2lb*#135(1)	**567.9**
ASME	MPasm = 568	**568**
LV	M0 = N2lb*#136(1)	**-462.9**
ASME	M0asm = -463	**-463**
'Result for Sigma step 8		**0**
LV	Tau = MPa2psi*#138(1)	**35963**
Asme	SigAsm = 36000	**36000**
'Result for Tau step 9		**0**
LV	Tau = MPa2psi*#140(1)	**3346**
Asme	TauAsm = 3350	**3350**
'Result for SigS step 10		**0**
LV	SigSm = MPa2psi*#142(1)	**-169.6**
ASME	SigSMasm = -170	**-170**
LV	SigSB = MPa2psi*#143(1)	**-17576**
ASME	SigSBasm = -17600	**-17600**
LV	SigS = MPa2psi*#144(1)	**17745**
ASME	SigSasm = 17700	**17700**
'Result for SigC step 10		**0**
LV	SigCm = MPa2psi*#146(1)	**1342**
ASME	SigCmasm = 1340	**1340**
LV	SigCb = MPa2psi*#147(1)	**25272**
ASME	SigCbasm = 25300	**25300**
LV	SigC = MPa2psi*#148(1)	**26615**
ASME	SigCasm = 26600	**26600**
		0
		0
		0

Example E4.18.1 - U-Tube Tubesheet Integral with Shell and Channel

A U-tube heat exchanger is to be designed with the tubesheet construction in accordance with configuration d as shown in VIII-1, Figure UHX-12.1, Configuration a.



(a) Configuration a:
Tubesheet Integral With Shell and Channel

- The shell side design conditions are -10 and 60 psig at 500°F.
- The tube side design conditions are -15 and 140 psig at 500°F.
- The tube material is SA-249 S31600 (Stainless Steel 316). The tubes are 0.75 in. outside diameter and 0.065 in. thick and are to be full-strength welded with no credit taken for expansion.
- The tubesheet material is SA-240 S31600 (Stainless Steel 316) with no corrosion allowance on the tube side and no pass partition grooves. The tubesheet outside diameter is 12.939 in. The tubesheet has 76 tube holes on a 1.0 in. square pattern with one centerline pass lane. The largest center-to-center distance between adjacent tube rows is 2.25 in., and the radius to the outermost tube hole center is 5.438 in.
- The shell material is SA-312 S31600 (Stainless Steel 316) welded pipe. The shell inside diameter is 12.39 in. and the shell thickness is 0.18 in.
- The channel material is SA-240 S31600 (Stainless Steel 316). The channel inside diameter is 12.313 in. and the channel thickness is 0.313 in.

Data Summary

The data summary consists of those variables from the nomenclature (see VIII-1, paragraphs UHX11.3 and UHX-12.3) that are applicable to this configuration.

The data for VIII-1, paragraph UHX-11.3 is:

c_t = 0 in.
d_t = 0.75 in.
E = 25.8E106 psi from Table TM-1 of Section II, Part D at 500°F
= 25.8E106 psi from Table TM-1 of Section II, Part D at 500°F
h_g = 0 in.
p = 1.0 in.
r_o = 5.438 in.
S = 18,000 psi from Table1A of Section II, Part D at 500°F
S_t = 18,000 psi from TablelA of Section II, Part D at 500°F (for seamless tube, SA-213)
t, = 0.065 in.
U_{L1} = 2.25 in.
ρ = 0 for no tube expansion

The data for VIII-1, paragraph UHX-12.3 is:

A = 12.939in.
D =12.313in
Ds =12.39 in.
E = 25.8E106 psi from Table TM-1 of Section II, Part D at 500°F
E_c = 25.8E106 psi from Table TM-1 of Section II, Part D at 500°F
E_s = 25.8E106 psi from Table TM-1 of Section II, Part D at 500°F
$P_{sd,max}$ = 60 psig
$P_{sd,min}$ = -10 psig
$P_{td,max}$ =140 psig
$P_{td,min}$ = -15 psig
S =18,000 psi from Table 1A of Section II, Part D at 500°F
S_c =18,000 psi from Table 1A of Section II, Part D at 500°F
S_s =18,000 psi from Table 1A of Section II, Part D at 500°F (for seamless pipe, SA-312)
t_c = 0.313 in.
t_s = 0.18 in.
v_c = 0.3
v_s = 0.3

E 4.18.1
ASME UHX-12 U-Tubesheets ASME BPVC Edition 2017

U-Tubesheet Heat Exchanger according to ASME-UHX-12

Configuration of the tubesheet (a, b, ..., f)	Type	a	(a-f)
Tubesheet integral with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operation pressure shell side	P_s	-10	psi
Internal operation pressure tube side	P_t	140	psi
Internal test pressure shell side	P_{sp}	-13	psi
Internal test pressure tube side	P_{tp}	182	psi
Load case (1=Operation, 2+3=Test at 20°C, 4=other)		1	
load case: operation			
Calculation case UHX12.4(a) (1: Ps=0, 2: Pt=0, 3:Differ.)		3	(1-3)
Shell and tube side pressure acting			

Material tubesheet	S31600-SA-240-316-Class:-Size:
Material shell (Type abc)	S31600-SA-312-TP316-Class:-Size:
Material tubes	S31600-SA-213-TP316-Class:-Size:
Mat. channel (Type aef)	S31600-SA-240-316-Class:-Size:

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	500	°F	500	°F	500	°F	500	°F
Thickness	0.521	in	0.18	in	0.065	in	0.313	in
Outside diameter	12.94	in	12.75	in	0.75	in	12.94	in
Strength	18072	psi	18072	psi	18072	psi	18072	psi
Safety fac.	1		1		1		1	
E-module	2.587e+7	psi	2.587e+7	psi	2.587e+7	psi	2.587e+7	psi
Allow. c_1	0	in	0	in	0	in	0	in
Corr.all. c_2	0	in	0	in	0	in	0	in
Poisson's ratio		v	0.3				0.3	
Therm.exp.	9.678	1E-6/°F	9.678	1E-6/°F	9.678	1E-6/°F	9.678	1E-6/°F
Yield str.	19986	psi	19986	psi	19986	psi	19986	psi
Limit temperature	1103	°F	1103	°F	1103	°F	1103	°F
All.Stress	**18072**	psi	**18072**	psi	**18072**	psi	**18072**	psi
Pr.+sec.st	**54215**	psi	**54215**	psi	**54215**	psi	**54215**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	26759	psi	26759	psi	26759	psi	26759	psi
Safety fac.	1		1		1		1	
E-module	2.828e+7	psi	2.828e+7	psi	2.828e+7	psi	2.828e+7	psi
Yield str.	29733	psi	29733	psi	29733	psi	29733	psi
Tensile str.	74694	psi	74694	psi	74694	psi	74694	psi

Mean contact diameter tubesheet-flange (Type cf)	G_1		in
Bolt circle diameter (Type bcdef)	C		in
Number of bolts	n		-
Bolt root diameter	d_B		in
Total bolt area	A_b		in²
Bolt material			
Strength for operation	K_s		psi
Strength at 20°C (or test)	K_{sp}		psi
Safety for operation	S_s		-
Safety at 20°C (or test)	S_{sp}		-
Stress enhancement factor acc. App. S	F_s	1.5	-
Allowable testing stress for bolts	σ		psi
Yield stress (20°C)	Rp0,2RT		psi
Flange material			
Strength operation	K_f		psi
Strength at 20°C (or test)	K_{fp}		psi
Safety for operation	S_f		-
Safety at 20°C (or test)	S_{fp}		-

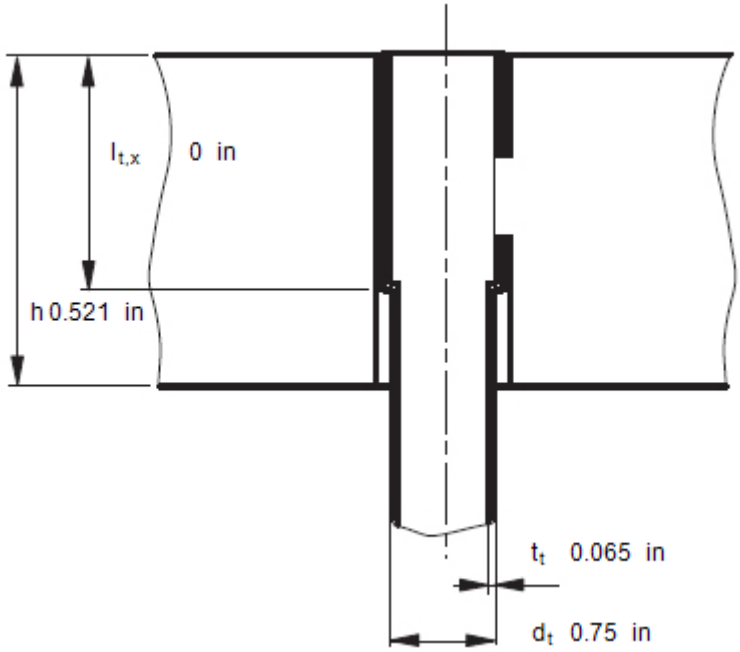
		Shell		Channel	
Gasket		**Type d,e,f**		**Type b,c,d**	
Contact outside diameter	G_a		in		in
Contact inside diameter	Gi		in		in
Basic seating width	b_0		in		in
Gasket factor (Table 2-5.1)	m				
Gasket seating pressure	Y		psi		psi
Diameter of gasket force	G		in		in
Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Initial gasket force	W	**0**	lbf	**0**	lbf
Gasket operation force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
Flange thickness	h_r	**0**	in	**0**	in

Bolt area in² :

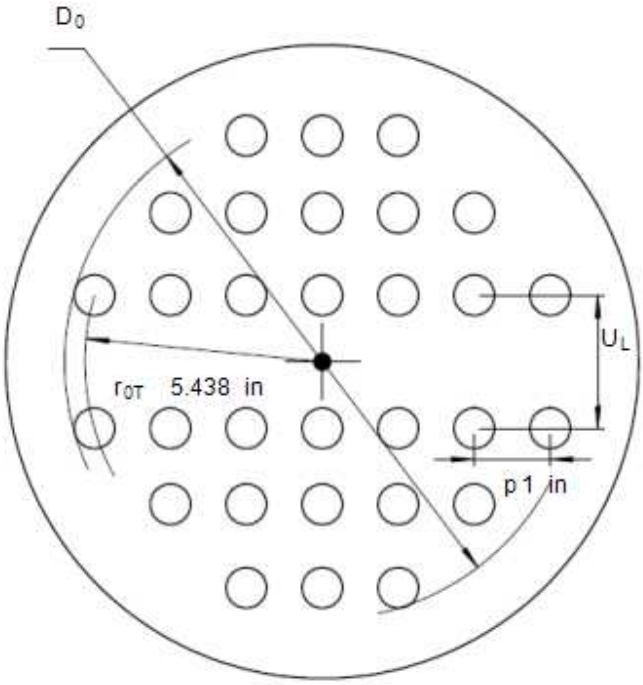
Additional specifications for geometry and loading

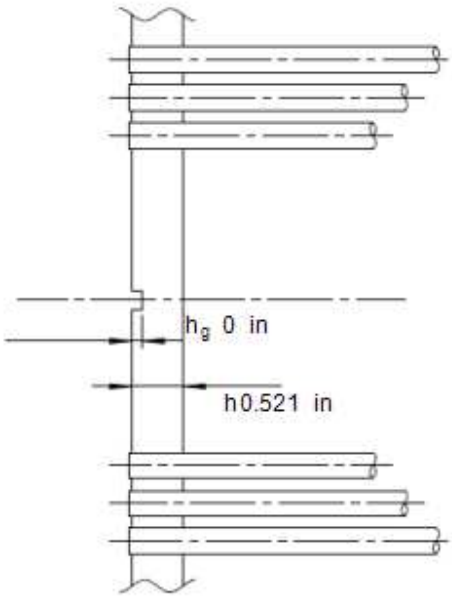
Tubesheet

12.6 Calculation as simply supported tubesheet		N	(Y,N)
Tube joint	(1=expanded, 2=backside-welded)	1	(1, 2)
Tube hole pattern	(1=Triangle, 2=Square)	2	(1, 2)



Expanded length of tube in tubesheet		$l_{t,x}$	0	in
Radius to outermost tube hole center	UHX-11.1a	r_{0T}	5.438	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by Cp	UHX-12.2	A_p		in²
Tube hole pitch (Center distance)		p	1	in





Untubed area UL1·LL1+UL2·LL2...	UHX-11.2	A_L	26.17	in²
Depth of pass partition groove		h_g	0	in
Length ratio of tube expansion ltx/h		ρ	**0**	

Results acc. to UHX-12

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	App.2-5	W_m	**0**	lbf
Channel thickness without allowances		t_c	**0.313**	in
Shell thickness without allowances		t_s	**0.18**	in
Recommended initial tubesheet thickness	UHX-12.4	h_{in}	**0.1206**	in
Tubesheet thickness without allowances > hin		h	**0.521**	in

Step 1 acc. to UHX 12.5

Equivalent diameter of outer tube limit circle		D_0	**11.63**	in
Basic ligament efficiency for shear		μ	**0.25**	
Effective tubeside pass partition groove depth		h_g'	**0**	in

Step 2

Ratio Ds/D0 (Type abc) or Gs/D0 (Type def)		ρ_S	**1.066**	
Ratio Dc/D0 (Type aef) or Gc/D0 (Type bcd)		ρ_C	**1.059**	
Tubesheet rim moment due to P_s and P_t		M_{TS}	**-160.4**	lbf

Step 3

Effective mod. elasticity tubesheet	UHX-11.2, 11.3	E*	**1.152e+7**	psi
Effective Poisson's ratio of tubesheet		v*	**0.2539**	
Effective tube pitch		p*	**1.152**	in
Effective ligament efficiency for bending		μ*	**0.349**	
Effective tube hole diameter		d*	**0.75**	in

Step 4

Coefficient for moment of shell	ω_S	**0.491**	in²
Coefficient for moment of channel	ω_C	**0.7559**	in²

Step 5

Diameter ratio = A/D0	K	**1.113**	
Coefficient	F	**9.406**	

Step 6

Rim moment	M*	**-49.62**	lbf

Step 7

Bending moment at periphery	M_p	**567.9**	lbf
Moment at the tubesheet center	M_0	**-462.9**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **35973** psi < **36143** psi = 2 · σ_B

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **3347** psi < **14457** psi = 0.8 · σ_B

Strength condition satisfied

Step 10: Absolute values of stress σS in the shell and und σC in the channel

σ_S = **17750** psi < **27107** psi = 1.5 · σ_{all}

$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ = **-169.6** psi + **-17580** psi

σ_C = **26621** psi < **27107** psi = 1.5 · σ_{all}

$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ = **1343** psi + **25278** psi

Shell length, uniform thickness > l_{Sm} = 0 or **2.688** in

Channel length, uniform thickness > l_{Cm} = 0 or **3.534** in

Strength condition acc. to UHX-12.5.10 satisfied

Step 11 option 3: If the strength condition of step 10 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 allows also the reduction of the elastic modulus of the shell and/or the channel.

Geometric conditions:

valid

Equations acc. to UHX-12.5 (in SI-Units)

12.4(c) If: Tubesheet thickness = 0.521 in < 0.75 in
= Tube outside diameter, the tube sheet deflection should be considered

Allowable primary and secondary stress in the shell acc. to UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2·Yield strength (b) for operation
54215 psi = 3· **18072** psi or 2· 19986 psi
(b) under the condition: σ_{all} not in the creep range
T= **500** °F < 1103 °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 1.651 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 1.651 \text{ mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 13.23 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 13.23 \text{ mm}$$

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot |p_T - p_S| =$$

(estimation, deleted Add.2009)

$$\frac{1}{(4 \cdot 0.25)} \cdot \frac{295.3 \text{ mm}}{(0.8 \cdot 124.6 \text{ N/mm}^2)} \cdot |0.9653 \text{ N/mm}^2 - -0.06895 \text{ N/mm}^2| = 3.064 \text{ mm}$$

UHX-12.5.1 Step 1

$$D_0 = 2 \cdot r_0 + d_{aT} = 2 \cdot 138.1 \text{ mm} + 19.05 \text{ mm} = 295.3 \text{ mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(25.4 \text{ mm} - 19.05 \text{ mm})}{25.4 \text{ mm}} = 0.25$$

$$0 \text{ mm} = Max\begin{cases}(0 \text{ mm} - 0 \text{ mm}) \\ 0\end{cases}$$

UHX-12.5.2 Step 2

$$M_{TS120} = \frac{D0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S{}^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho C^2 + 1) \cdot P_t\right] =$$

$$\frac{(295.3 \text{ mm})^2}{16} \cdot [((1.066 - 1)((1.066)^2 + 1) \cdot -0.06895 \text{ N/mm}^2) - (1.059 - 1)((1.059)^2 + 1) \cdot 0.9653 \text{ N/mm}^2] = -713.3 \text{ N}$$

UHX-12.5.3 Step 3

$$\rho = \frac{I_{t,x}}{h} = \frac{0 \text{ mm}}{13.23 \text{ mm}} = 0$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D0^2}}} = \frac{25.4 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 16884 \text{ mm}^2}{\pi \cdot (295.3 \text{ mm})^2}}} = 29.26 \text{ mm}$$

$$d^* = Max\begin{cases}d1^* \\ d2^*\end{cases}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05 \text{ mm} - 2 \cdot 1.651 \text{ mm}) = d1^*$$

$$d2^*=d_T-2\cdot t_T\cdot\frac{E_T}{E_B}\cdot\frac{\sigma_T}{\sigma_B}\cdot\rho=19.05\text{ mm}-2\cdot 1.651\text{ mm}\cdot\frac{178400\text{ N/mm²}}{178400\text{ N/mm²}}\cdot\frac{124.6\text{ N/mm²}}{124.6\text{ N/mm²}}\cdot 0=d2^*$$

$$\mu^*=\frac{(p^*-d^*)}{d^*}=\frac{(29.26\text{ mm}-19.05\text{ mm})}{19.05\text{ mm}}=0.349$$

UHX-12.5.4 Step 4

Type abc:	β_S	**14.5**	1/ft	k_S	**33401**	lbf	λ_S	**3.209e+7**	psi
Type aef:	β_C	**10.97**	1/ft	k_C	**132878**	lbf	λ_C	**1.104e+8**	psi

UHX-12.5.5 Step 5

$$F=\frac{(1-v^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.2539)}{79427\text{ N/mm²}}\cdot(221270\text{ N/mm²}+760973\text{ N/mm²}+178400\text{ N/mm²}\cdot\ln(1.113))=9.406$$

UHX-12.5.6 Step 6

$$M^*=M_{TS}+\omega_C\cdot P_c-\omega_S\cdot P_s+M_{add}=$$

$$-713.3\text{ N}+487.7\text{ mm²}\cdot 0.9653\text{ N/mm²}-316.8\text{ mm²}\cdot -0.06895\text{ N/mm²}+0\text{ N}=-220.7\text{ N}$$

M_{add} = 0 = **0** lbf

UHX-12.5.6 acc. UHX-12.6

$$Mfd^*=M_{TS}+M_{add}=-713.3\text{ N}+0\text{ N}=-713.3\text{ N}$$

Step 8: Strength condition for the bending stress in the tubesheet:

	σ		**or**	**σ acc. UHX12.6**		**< 2· σ_B**		
σ =	**35973**	psi	or	**-67799**	psi	< 2·	**18072**	psi

Step 9: Strength condition for the shear stress in the tubesheet:

	τ		**or**	**τ acc. UHX12.6**		**< 0.8· σ_B**		
τ =	**3347**	psi	or	**3347**	psi	< 0.8·	**18072**	psi

Strength condition satisfied

If the strength condition in step 8 or 9 is violated, the tubesheet thickness must be increased.
Actual thickness 0.521 in

Step 10: Absolute values of stresses σ_S in the shell and σ_C in the channel

in MPa:	**σ_m**		**σ_b**			**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**-1.169**	+	**-121.2**	=	**122.4**	< 1.5·	**124.6**	or	**373.8**
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**9.259**	+	**174.3**	=	**183.5**	< 1.5·	**124.6**	or	**373.8**

*) Simply supported (N) acc. UHX-12.6

Strength condition acc. to UHX-12.5.10 satisfied

Step 11: The modulus of elasticity is reduced: N (Y=Yes,N=No)

Modulus of elasticity	elastic	Option 3	
Shell	**2.587e+7** psi	**2.587e+7**	psi
Channel	**2.587e+7** psi	**2.587e+7**	psi

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S\cdot\sqrt{(1.5\cdot\sigma_{allS}/\sigma_S)}$, under the conditions:

σ_S = **17750** psi ≤ **54215** psi = S_{PSs}

with the allowable primary+secondary stress S_{PSs}, if the allowable stress σ_{allS} is outside of the creep range!

Analogously for the channel:

σ_C = **26621** psi ≤ **54215** psi = S_{PSc}

E.4.18.2
ASME UHX-12 U-Tubesheets ASME BPVC Edition 2017

U-Tubesheet Heat Exchanger according to ASME-UHX-12

Configuration of the tubesheet (a, b, ..., f)	Type d		(a-f)
Tubesheet gasketed with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operation pressure shell side	P_s	-15	psi
Internal operation pressure tube side	P_t	135	psi
Internal test pressure shell side	P_{sp}	-19.5	psi
Internal test pressure tube side	P_{tp}	175.5	psi
Load case (1=Operation, 2+3=Test at 20°C, 4=other)		1	
load case: operation			
Calculation case UHX12.4(a) (1: Ps=0, 2: Pt=0, 3:Differ.)		3	(1-3)
Shell and tube side pressure acting			
Material tubesheet	K02801-SA-285-C-Class:-Size:		
Material shell (Type abc)			
Material tubes	C44300-SB-111--Class:O61-Size:<75		
Mat. channel (Type aef)			

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	300	°F	300	°F	300	°F		°F
Thickness	**1.405**	in		in	0.065	in		in
Outside diameter	20	in		in	0.625	in		in
Strength	15664	psi		psi	9993	psi		psi
Safety fac.	1				1			
E-module	2.829e+7	psi	0	psi	1.538e+7	psi		psi
Allow. c_1	0	in		in	0	in		in
Corr.all. c_2	0.125	in		in	0	in		in
Poisson's ratio		v	0.3				0.3	
Therm.exp.	6.885	1E-6/°F		1E-6/°F	9.995	1E-6/°F		1E-6/°F
Yield str.	26561	psi		psi	0	psi		psi
Limit temperature	752	°F		°F	347	°F		°F
All.Stress	**15664**	psi	**0**	psi	**9993**	psi	**0**	psi
Pr.+sec.st	**53122**	psi	**0**	psi	**29979**	psi	**0**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	26759	psi	0	psi	13053	psi	0	psi
Safety fac.	1				1			
E-module	2.93e+7	psi		psi	1.595e+7	psi		psi
Yield str.	29733	psi		psi	14504	psi		psi
Tensile str.	55114	psi		psi	44961	psi		psi

Mean contact diameter tubesheet-flange (Type cf)		G_1		in
Bolt circle diameter (Type bcdef)		C	21.65	in
Number of bolts		n		-
Bolt root diameter		d_B		in
Total bolt area		A_b		in²
Bolt material	K50100-SA-193-B5-Class:-Size:<=100			
Strength for operation		K_s	20015	psi
Strength at 20°C (or test)		K_{sp}	20015	psi
Safety for operation		S_s	1	-
Safety at 20°C (or test)		S_{sp}	1	-
Stress enhancement factor acc. App. S		F_s	0	-
Allowable testing stress for bolts		σ	**0**	psi
Yield stress (20°C)		Rp0,2RT	0	psi
Flange material	K02801-SA-285-C-Class:-Size:			
Strength operation		K_f	15664	psi
Strength at 20°C (or test)		K_{fp}	15664	psi
Safety for operation		S_f	1	-
Safety at 20°C (or test)		S_{fp}	1	-

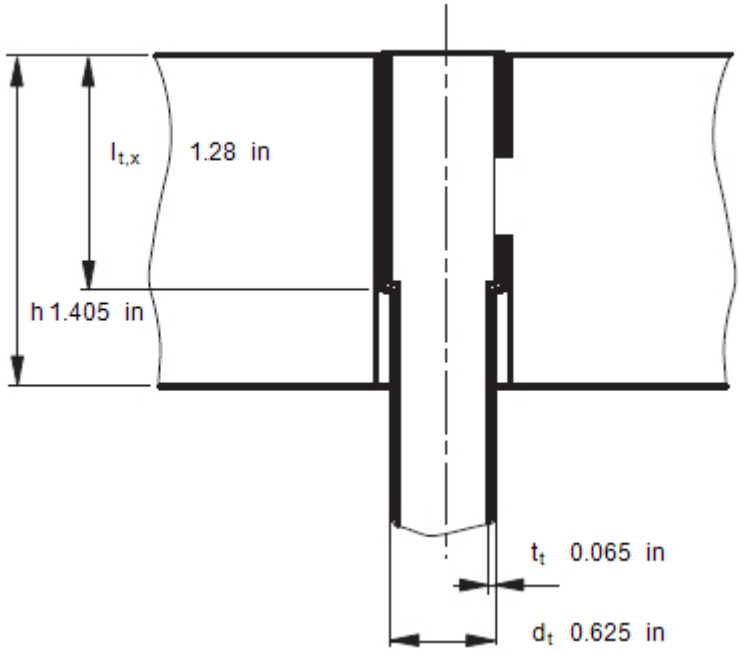
		Shell		Channel	
Gasket		**Type d,e,f**		**Type b,c,d**	
Contact outside diameter	G_a		in		in
Contact inside diameter	Gi		in		in
Basic seating width	b_0		in		in
Gasket factor (Table 2-5.1)	m				
Gasket seating pressure	Y		psi		psi
Diameter of gasket force	G	19	in	19	in
Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Initial gasket force	W	147000	lbf	162000	lbf
Gasket operation force	W	147000	lbf	162000	lbf
Total req. bolt root area	A_m	**7.344**	in²	**8.094**	in²
Flange thickness	h_r		in		in

Bolt area in² :

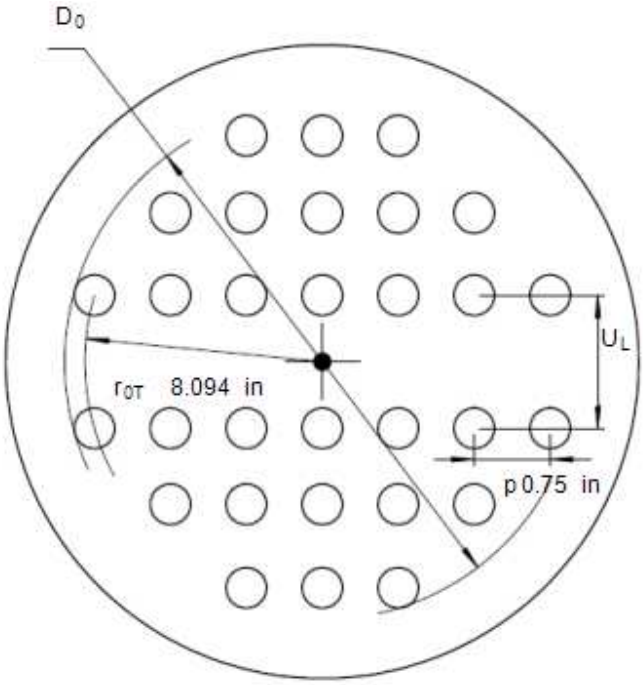
Additional specifications for geometry and loading

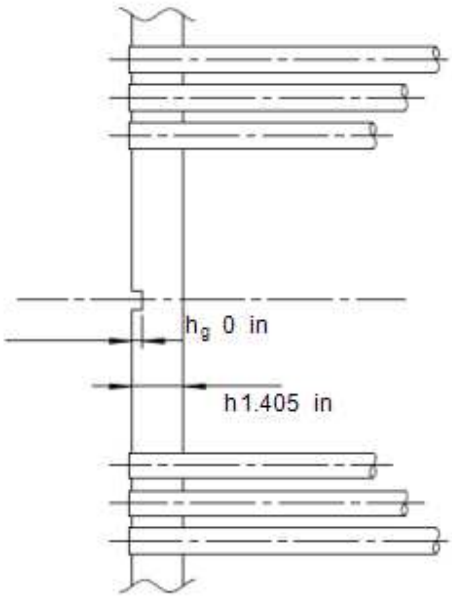
Tubesheet

12.6 Calculation as simply supported tubesheet		N	(Y,N)
Tube joint	(1=expanded, 2=backside-welded)	1	(1, 2)
Tube hole pattern	(1=Triangle, 2=Square)	1	(1, 2)



Expanded length of tube in tubesheet		$l_{t,x}$	**1.28**	in
Radius to outermost tube hole center	UHX-11.1a	r_{0T}	8.094	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by Cp	UHX-12.2	A_p		in²
Tube hole pitch (Center distance)		p	0.75	in





Untubed area UL1·LL1+UL2·LL2...	UHX-11.2	A_L	29.42	in²
Depth of pass partition groove		h_g	0	in
Length ratio of tube expansion ltx/h		ρ	1	

Results acc. to UHX-12

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	App.2-5	W_m	162000	lbf
Channel thickness without allowances		t_c		in
Shell thickness without allowances		t_s		in
Recommended initial tubesheet thickness	UHX-12.4	h_{in}	**0.3019**	in
Tubesheet thickness without allowances > hin		h	1.28	in

Step 1 acc. to UHX 12.5

Equivalent diameter of outer tube limit circle	D_0	**16.81**	in
Basic ligament efficiency for shear	μ	**0.1667**	
Effective tubeside pass partition groove depth	h_g'	**0**	in

Step 2

Ratio Ds/D0 (Type abc) or Gs/D0 (Type def)	ρ_S	**1.13**	
Ratio Dc/D0 (Type aef) or Gc/D0 (Type bcd)	ρ_C	**1.13**	
Tubesheet rim moment due to P_s and P_t	M_{TS}	**-785**	lbf

Step 3

Effective mod. elasticity tubesheet	UHX-11.2, 11.3	E*	**7503584**	psi
Effective Poisson's ratio of tubesheet		v*	**0.3576**	
Effective tube pitch		p*	**0.8052**	in
Effective ligament efficiency for bending		μ*	**0.2798**	
Effective tube hole diameter		d*	**0.5799**	in

Step 4

Coefficient for moment of shell	ω_S	**0**	in²
Coefficient for moment of channel	ω_C	**0**	in²

Step 5

Diameter ratio = A/D0	K	**1.19**	
Coefficient	F	**0.4204**	

Step 6

Rim moment	M*	**-785**	lbf

Step 7

Bending moment at periphery	M_p	**-160.4**	lbf
Moment at the tubesheet center	M_0	**-2385**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **-31211** psi < **31328** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **2955** psi < **12531** psi = $0.8 \cdot \sigma_B$

Strength condition satisfied

Step 10: Absolute values of stress σS in the shell and und σC in the channel

σ_S = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ = **0** psi + **0** psi

σ_C = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ = **0** psi + **0** psi

Shell length, uniform thickness > l_{Sm} = 0 or in

Channel length, uniform thickness > l_{Cm} = 0 or in

UHX-12.5.10 not required for configuration d

Step 11 option 3: If the strength condition of step 10 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 allows also the reduction of the elastic modulus of the shell and/or the channel.

Geometric conditions:

valid

Equations acc. to UHX-12.5 (in SI-Units)

12.4(c) If: Tubesheet thickness = **1.405** in < 0.625 in
= Tube outside diameter, the tube sheet deflection should be considered

Allowable primary and secondary stress in the shell acc. to UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2·Yield strength (b) for operation
0 psi = 3· **0** psi or 2· psi
(b) under the condition: σ_{all} not in the creep range
T= **300** °F < °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 1.651 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 1.651 \text{ mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 35.69 \text{ mm} - 0 \text{ mm} - 3.175 \text{ mm} = 32.51 \text{ mm}$$

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot |p_T - p_S| =$$

(estimation, deleted Add.2009)

$$\frac{1}{(4 \cdot 0.1667)} \cdot \frac{427.1 \text{ mm}}{(0.8 \cdot 108 \text{ N/mm}^2)} \cdot |0.9308 \text{ N/mm}^2 - -0.1034 \text{ N/mm}^2| = 7.668 \text{ mm}$$

UHX-12.5.1 Step 1

$$D_0 = 2 \cdot r_0 + d_{aT} = 2 \cdot 205.6 \text{ mm} + 15.88 \text{ mm} = 427.1 \text{ mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(19.05 \text{ mm} - 15.88 \text{ mm})}{19.05 \text{ mm}} = 0.1667$$

$$0 \text{ mm} = Max\begin{Bmatrix}(0 \text{ mm} - 0 \text{ mm}) \\ 0\end{Bmatrix}$$

UHX-12.5.2 Step 2

$$M_{TS120} = \frac{D0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S{}^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho C^2 + 1) \cdot P_t\right] =$$

$$\frac{(427.1 \text{ mm})^2}{16} \cdot [((1.13 - 1)((1.13)^2 + 1) \cdot -0.1034 \text{ N/mm}^2) - (1.13 - 1)((1.13)^2 + 1) \cdot 0.9308 \text{ N/mm}^2] = -3492 \text{ N}$$

UHX-12.5.3 Step 3

$$\rho = \frac{I_{t,x}}{h} = \frac{32.51 \text{ mm}}{32.51 \text{ mm}} = 1$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D0^2}}} = \frac{19.05 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 18979 \text{ mm}^2}{\pi \cdot (427.1 \text{ mm})^2}}} = 20.45 \text{ mm}$$

$$d^* = Max\begin{Bmatrix}d1^* \\ d2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (15.88 \text{ mm} - 2 \cdot 1.651 \text{ mm}) = d1^*$$

$$d2^*=d_T-2\cdot t_T\cdot\frac{E_T}{E_B}\cdot\frac{\sigma_T}{\sigma_B}\cdot\rho=15.88\text{ mm}-2\cdot 1.651\text{ mm}\cdot\frac{106044\text{ N/mm²}}{195067\text{ N/mm²}}\cdot\frac{68.9\text{ N/mm²}}{108\text{ N/mm²}}\cdot 1=d2^*$$

$$\mu^*=\frac{(p^*-d^*)}{d^*}=\frac{(20.45\text{ mm}-14.73\text{ mm})}{14.73\text{ mm}}=0.2798$$

UHX-12.5.4 Step 4

Type abc:	β_S	1/ft	k_S	lbf	λ_S	**0**	psi
Type aef:	β_C	1/ft	k_C	lbf	λ_C	**0**	psi

UHX-12.5.5 Step 5

$$F=\frac{(1-v^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.3576)}{51736\text{ N/mm²}}\cdot(0\text{ N/mm²}+0\text{ N/mm²}+195067\text{ N/mm²}\cdot\ln(1.19))=0.4204$$

UHX-12.5.6 Step 6

$$M^*=M_{TS}+\omega_C\cdot P_c-\omega_S\cdot P_s+M_{add}=-3492\text{ N}+0\text{ mm²}\cdot 0.9308\text{ N/mm²}-0\text{ mm²}\cdot -0.1034\text{ N/mm²}+0\text{ N}=-3492\text{ N}$$

M_{add} = (Gc-Gs)*Wm/(2* PI *D0) = **0** lbf

UHX-12.5.6 acc. UHX-12.6

$$Mfd^*=M_{TS}+M_{add}=-3492\text{ N}+0\text{ N}=-3492\text{ N}$$

Step 8: Strength condition for the bending stress in the tubesheet:

	σ		**or**	**σ acc. UHX12.6**		**< 2· σ_B**	
σ =	**-31211**	psi	or	**-31211**	psi	< 2· **15664**	psi

Step 9: Strength condition for the shear stress in the tubesheet:

	τ		**or**	**τ acc. UHX12.6**		**< 0.8· σ_B**	
τ =	**2955**	psi	or	**2955**	psi	< 0.8· **15664**	psi

Strength condition satisfied

If the strength condition in step 8 or 9 is violated, the tubesheet thickness must be increased.
Actual thickness **1.405** in

Step 10: Absolute values of stresses σ_S in the shell and σ_C in the channel in MPa:

	σ_m		**σ_b**			**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**0**	+	**0**	=	**0**	< 1.5· **0**	or		**0**
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**0**	+	**0**	=	**0**	< 1.5· **0**	or		**0**

*) Simply supported (N) acc. UHX-12.6

UHX-12.5.10 not required for configuration d

Step 11: The modulus of elasticity is reduced: N (Y=Yes,N=No)

Modulus of elasticity	elastic	Option 3	
Shell	**0** psi	**0**	psi
Channel	psi		psi

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S\cdot\sqrt{(1.5\cdot\sigma_{allS}/\sigma_S)}$, under the conditions:

σ_S = **0** psi ≤ **0** psi = S_{PSs}

with the allowable primary+secondary stress S_{PSs}, if the allowable stress σ_{allS} is outside of the creep range!

Analogously for the channel:

σ_C = **0** psi ≤ **0** psi = S_{PSc}

E 4.18.3
ASME UHX-12 U-Tubesheets ASME BPVC Edition 2017

U-Tubesheet Heat Exchanger according to ASME-UHX-12

Configuration of the tubesheet (a, b, ..., f)	Type d		(a-f)
Tubesheet gasketed with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operation pressure shell side	P_s	375	psi
Internal operation pressure tube side	P_t	75	psi
Internal test pressure shell side	P_{sp}	487.6	psi
Internal test pressure tube side	P_{tp}	97.5	psi
Load case (1=Operation, 2+3=Test at 20°C, 4=other)		1	
load case: operation			
Calculation case UHX12.4(a) (1: Ps=0, 2: Pt=0, 3:Differ.)		3	(1-3)
Shell and tube side pressure acting			
Material tubesheet	K02700-SA-516-70-Class:-Size:		
Material shell (Type abc)			
Material tubes	C70600-SB-111--Class:H55-Size:		
Mat. channel (Type aef)			

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	500	°F		°F	500	°F		°F
Thickness	**4.275**	in		in	0.049	in		in
Outside diameter	48.88	in		in	0.75	in		in
Strength	19957	psi		psi	7942	psi		psi
Safety fac.	1				1			
E-module	2.73e+7	psi	0	psi	1.66e+7	psi		psi
Allow. c_1	0	in		in	0	in		in
Corr.all. c_2	0.125	in		in	0	in		in
Poisson's ratio		v	0.3				0.3	
Therm.exp.	7.256	1E-6/°F		1E-6/°F	0	1E-6/°F		1E-6/°F
Yield str.	30980	psi		psi	29472	psi		psi
Limit temperature	752	°F		°F	500	°F		°F
All.Stress	**19957**	psi	**0**	psi	**7942**	psi	**0**	psi
Pr.+sec.st	**61960**	psi	**0**	psi	**23827**	psi	**0**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	33939	psi	0	psi	31328	psi	0	psi
Safety fac.	1				1			
E-module	2.93e+7	psi		psi	1.798e+7	psi		psi
Yield str.	37710	psi		psi	34809	psi		psi
Tensile str.	70343	psi		psi	44961	psi		psi

Mean contact diameter tubesheet-flange (Type cf)	G_1		in
Bolt circle diameter (Type bcdef)	C		in
Number of bolts	n		-
Bolt root diameter	d_B		in
Total bolt area	A_b		in²
Bolt material			
Strength for operation	K_s		psi
Strength at 20°C (or test)	K_{sp}		psi
Safety for operation	S_s		-
Safety at 20°C (or test)	S_{sp}		-
Stress enhancement factor acc. App. S	F_s	1	-
Allowable testing stress for bolts	σ		psi
Yield stress (20°C)	Rp0,2RT		psi
Flange material			
Strength operation	K_f		psi
Strength at 20°C (or test)	K_{fp}		psi
Safety for operation	S_f		-
Safety at 20°C (or test)	S_{fp}		-

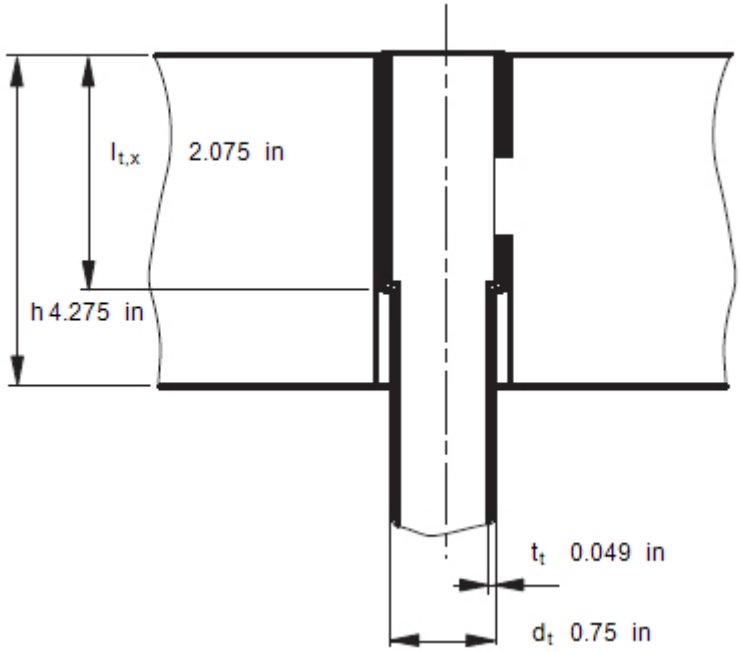
		Shell		Channel	
Gasket		**Type d,e,f**		**Type b,c,d**	
Contact outside diameter	G_a		in		in
Contact inside diameter	Gi		in		in
Basic seating width	b_0		in		in
Gasket factor (Table 2-5.1)	m				
Gasket seating pressure	Y		psi		psi
Diameter of gasket force	G	43.5	in	44.88	in
Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Initial gasket force	W	675000	lbf	584000	lbf
Gasket operation force	W	675000	lbf	584000	lbf
Total req. bolt root area	A_m		in²		in²
Flange thickness	h_r		in		in

Bolt area in² :

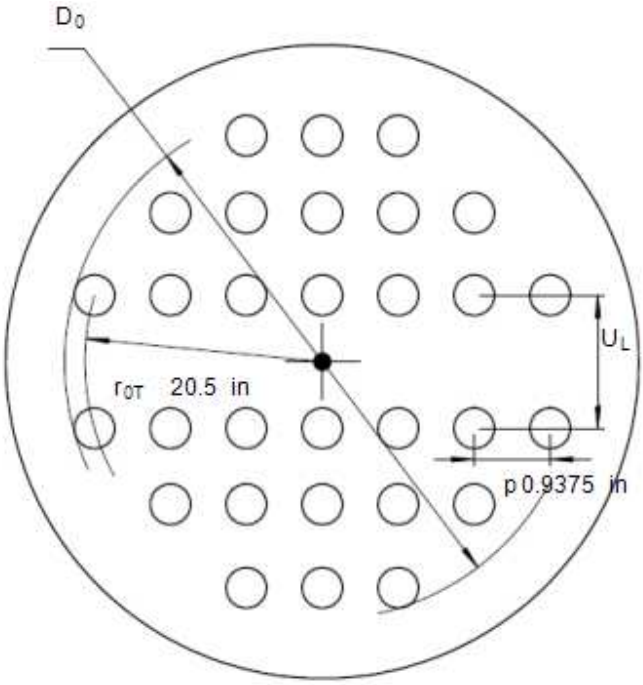
Additional specifications for geometry and loading

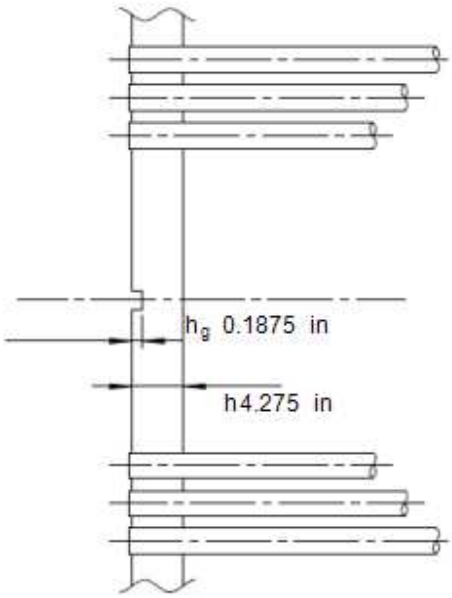
Tubesheet

12.6 Calculation as simply supported tubesheet		N	(Y,N)
Tube joint	(1=expanded, 2=backside-welded)	1	(1, 2)
Tube hole pattern	(1=Triangle, 2=Square)	1	(1, 2)



Expanded length of tube in tubesheet		$l_{t,x}$	**2.075**	in
Radius to outermost tube hole center	UHX-11.1a	r_{0T}	20.5	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by Cp	UHX-12.2	A_p		in²
Tube hole pitch (Center distance)		p	0.9375	in





Untubed area UL1·LL1+UL2·LL2...	UHX-11.2	A_L	93.94	in²
Depth of pass partition groove		h_g	0.1875	in
Length ratio of tube expansion ltx/h		ρ	0.5	

Results acc. to UHX-12

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	App.2-5	W_m	675000	lbf
Channel thickness without allowances		t_c		in
Shell thickness without allowances		t_s		in
Recommended initial tubesheet thickness	UHX-12.4	h_{in}	**0.9806**	in
Tubesheet thickness without allowances > hin		h	4.15	in

Step 1 acc. to UHX 12.5

Equivalent diameter of outer tube limit circle	D_0	**41.75**	in
Basic ligament efficiency for shear	μ	**0.2**	
Effective tubeside pass partition groove depth	h_g'	**0.0625**	in

Step 2

Ratio Ds/D0 (Type abc) or Gs/D0 (Type def)	ρ_S	**1.042**	
Ratio Dc/D0 (Type aef) or Gc/D0 (Type bcd)	ρ_C	**1.075**	
Tubesheet rim moment due to P_s and P_t	M_{TS}	**2251**	lbf

Step 3

Effective mod. elasticity tubesheet	UHX-11.2, 11.3	E*	**5574051**	psi
Effective Poisson's ratio of tubesheet		v*	**0.407**	
Effective tube pitch		p*	**0.9714**	in
Effective ligament efficiency for bending		μ*	**0.2401**	
Effective tube hole diameter		d*	**0.7381**	in

Step 4

Coefficient for moment of shell	ω_S	**0**	in²
Coefficient for moment of channel	ω_C	**0**	in²

Step 5

Diameter ratio = A/D0	K	**1.171**	
Coefficient	F	**0.4578**	

Step 6

Rim moment	M*	**5802**	lbf

Step 7

Bending moment at periphery	M_p	**-1152**	lbf
Moment at the tubesheet center	M_0	**26686**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **39906** psi < **39914** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **3773** psi < **15966** psi = $0.8 \cdot \sigma_B$

Strength condition satisfied

Step 10: Absolute values of stress σS in the shell and und σC in the channel

σ_S = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ = **0** psi + **0** psi

σ_C = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ = **0** psi + **0** psi

Shell length, uniform thickness > l_{Sm} = 0 or in

Channel length, uniform thickness > l_{Cm} = 0 or in

UHX-12.5.10 not required for configuration d

Step 11 option 3: If the strength condition of step 10 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 allows also the reduction of the elastic modulus of the shell and/or the channel.

Geometric conditions:

valid

Equations acc. to UHX-12.5 (in SI-Units)

12.4(c) If: Tubesheet thickness = **4.275** in < 0.75 in
= Tube outside diameter, the tube sheet deflection should be considered

Allowable primary and secondary stress in the shell acc. to UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2·Yield strength (b) for operation
0 psi = 3· **0** psi or 2· psi
(b) under the condition: σ_{all} not in the creep range
T= **500** °F < °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 1.245\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 1.245\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 108.6\ \text{mm} - 0\ \text{mm} - 3.175\ \text{mm} = 105.4\ \text{mm}$$

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot |p_T - p_S| =$$

(estimation, deleted Add.2009)

$$\frac{1}{(4 \cdot 0.2)} \cdot \frac{1060\ \text{mm}}{(0.8 \cdot 137.6\ \text{N/mm}^2)} \cdot |0.5171\ \text{N/mm}^2 - 2.586\ \text{N/mm}^2| = 24.91\ \text{mm}$$

UHX-12.5.1 Step 1

$$D_0 = 2 \cdot r_0 + d_{aT} = 2 \cdot 520.7\ \text{mm} + 19.05\ \text{mm} = 1060\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(23.81\ \text{mm} - 19.05\ \text{mm})}{23.81\ \text{mm}} = 0.2$$

$$1.587\ \text{mm} = Max\begin{Bmatrix}(4.762\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix}$$

UHX-12.5.2 Step 2

$$M_{TS120} = \frac{D0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S{}^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho C^2 + 1) \cdot P_t\right] =$$

$$\frac{(1060\ \text{mm})^2}{16} \cdot [((1.042 - 1)((1.042)^2 + 1) \cdot 2.586\ \text{N/mm}^2) - (1.075 - 1)((1.075)^2 + 1) \cdot 0.5171\ \text{N/mm}^2] = 10013\ \text{N}$$

UHX-12.5.3 Step 3

$$\rho = \frac{I_{t,x}}{h} = \frac{52.71\ \text{mm}}{105.4\ \text{mm}} = 0.5$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D0^2}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 60605\ \text{mm}^2}{\pi \cdot (1060\ \text{mm})^2}}} = 24.67\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d1^* \\ d2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^*=d_T-2\cdot t_T\cdot\frac{E_T}{E_B}\cdot\frac{\sigma_T}{\sigma_B}\cdot\rho=19.05\text{ mm}-2\cdot 1.245\text{ mm}\cdot\frac{114454\text{ N/mm²}}{188200\text{ N/mm²}}\cdot\frac{54.76\text{ N/mm²}}{137.6\text{ N/mm²}}\cdot 0.5=d2^*$$

$$\mu^*=\frac{(p^*-d^*)}{d^*}=\frac{(24.67\text{ mm}-18.75\text{ mm})}{18.75\text{ mm}}=0.2401$$

UHX-12.5.4 Step 4

Type abc:	β_S	1/ft	k_S	lbf	λ_S	**0**	psi
Type aef:	β_C	1/ft	k_C	lbf	λ_C	**0**	psi

UHX-12.5.5 Step 5

$$F=\frac{(1-v^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.407)}{38432\text{ N/mm²}}\cdot(0\text{ N/mm²}+0\text{ N/mm²}+188200\text{ N/mm²}\cdot\ln(1.171))=0.4578$$

UHX-12.5.6 Step 6

$$M^*=M_{TS}+\omega_C\cdot P_c-\omega_S\cdot P_s+M_{add}=10013\text{ N}+0\text{ mm²}\cdot 0.5171\text{ N/mm²}-0\text{ mm²}\cdot 2.586\text{ N/mm²}+15795\text{ N}=25808\text{ N}$$

M_{add} = (Gc-Gs)*Wm/(2* PI *D0) = **3551** lbf

UHX-12.5.6 acc. UHX-12.6

$$Mfd^*=M_{TS}+M_{add}=10013\text{ N}+15795\text{ N}=25808\text{ N}$$

Step 8: Strength condition for the bending stress in the tubesheet:

σ		**or**	**σ acc. UHX12.6**		**< 2· σ_B**	
σ =	**39906** psi	or	**39906** psi		< 2·	**19957** psi

Step 9: Strength condition for the shear stress in the tubesheet:

τ		**or**	**τ acc. UHX12.6**		**< 0.8· σ_B**	
τ =	**3773** psi	or	**3773** psi		< 0.8·	**19957** psi

Strength condition satisfied

If the strength condition in step 8 or 9 is violated, the tubesheet thickness must be increased.
Actual thickness **4.275** in

Step 10: Absolute values of stresses σ_S in the shell and σ_C in the channel

in MPa:	**σ_m**		**σ_b**		**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**0**	+	**0**	=	**0** < 1.5·	**0**	or	**0**
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**0**	+	**0**	=	**0** < 1.5·	**0**	or	**0**

*) Simply supported (N) acc. UHX-12.6

UHX-12.5.10 not required for configuration d

Step 11: The modulus of elasticity is reduced: N (Y=Yes,N=No)

Modulus of elasticity	elastic	Option 3
Shell	**0** psi	**0** psi
Channel	psi	psi

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S\cdot\sqrt{(1.5\cdot\sigma_{allS}/\sigma_S)}$, under the conditions:

σ_S = **0** psi ≤ **0** psi = S_{PSs}

with the allowable primary+secondary stress S_{PSs}, if the allowable stress σ_{allS} is outside of the creep range!

Analogously for the channel:

σ_C = **0** psi ≤ **0** psi = S_{PSc}

E.4.18.4
ASME UHX-12 U-Tubesheets ASME BPVC Edition 2017

U-Tubesheet Heat Exchanger according to ASME-UHX-12

Configuration of the tubesheet (a, b, ..., f)	Type e		(a-f)
Tubesheet with flange, gasketed with shell, integral with channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operation pressure shell side	P_s	650	psi
Internal operation pressure tube side	P_t	650	psi
Internal test pressure shell side	P_{sp}		psi
Internal test pressure tube side	P_{tp}		psi
Load case (1=Operation, 2+3=Test at 20°C, 4=other)		1	
load case: operation			
Calculation case UHX12.4(a) (1: Ps=0, 2: Pt=0, 3:Differ.)		2	(1-3)
Shell side pressure acting (Pt=0)			
Material tubesheet	K02700-SA-516-70-Class:-Size:		
Material shell (Type abc)			
Material tubes	K01200-SA-179--Class:-Size:		
Mat. channel (Type aef)	K02700-SA-516-70-Class:-Size:		

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	400	°F		°F	400	°F	400	°F
Thickness	3.625	in		in	0.085	in	0.625	in
Outside diameter	37.25	in		in	0.75	in	32.25	in
Strength	20015	psi		psi	13401	psi	20015	psi
Safety fac.	1				1		1	
E-module	2.781e+7	psi	0	psi	2.781e+7	psi	2.781e+7	psi
Allow. c_1	0	in		in	0	in	0	in
Corr.all. c_2	0.125	in		in	0	in	0	in
Poisson's ratio		v	0.3				0.3	
Therm.exp.	7.07	1E-6/°F		1E-6/°F	7.07	1E-6/°F	7.07	1E-6/°F
Yield str.	32530	psi		psi	22258	psi	32530	psi
Limit temperature	752	°F		°F	752	°F	752	°F
All.Stress	**20015**	psi	0	psi	**13401**	psi	**20015**	psi
Pr.+sec.st	**65061**	psi	0	psi	**44517**	psi	**65060**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	33939	psi	0	psi	23496	psi	33939	psi
Safety fac.	1				1		1	
E-module	2.93e+7	psi		psi	2.93e+7	psi	2.93e+7	psi
Yield str.	37710	psi		psi	26107	psi	37710	psi
Tensile str.	70343	psi		psi	47137	psi	70343	psi

Mean contact diameter tubesheet-flange (Type cf)	G_1		in
Bolt circle diameter (Type bcdef)	C	35	in
Number of bolts	n		-
Bolt root diameter	d_B		in
Total bolt area	A_b		in²
Bolt material			
Strength for operation	K_s		psi
Strength at 20°C (or test)	K_{sp}		psi
Safety for operation	S_s		-
Safety at 20°C (or test)	S_{sp}		-
Stress enhancement factor acc. App. S	F_s	1	-
Allowable testing stress for bolts	σ		psi
Yield stress (20°C)	Rp0,2RT		psi
Flange material			
Strength operation	K_f		psi
Strength at 20°C (or test)	K_{fp}		psi
Safety for operation	S_f		-
Safety at 20°C (or test)	S_{fp}		-

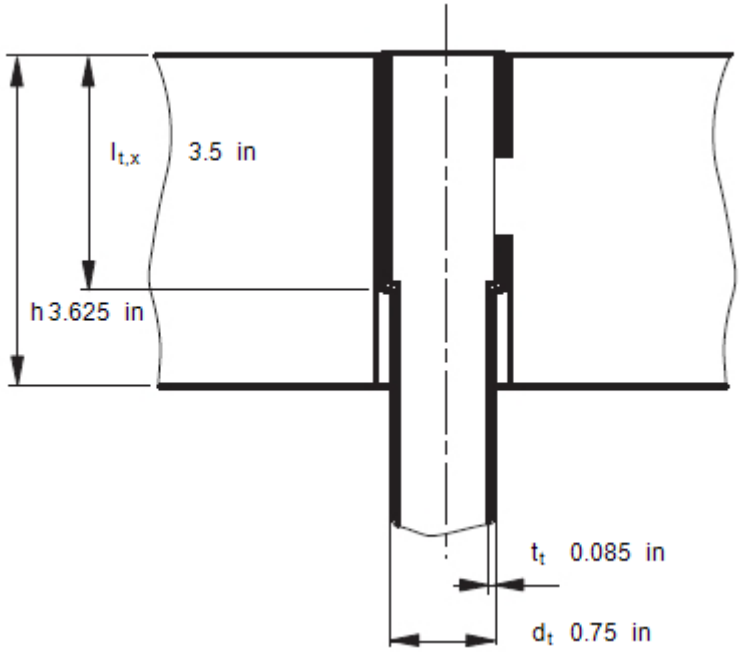
		Shell		Channel	
Gasket		**Type d,e,f**		**Type b,c,d**	
Contact outside diameter	G_a		in		in
Contact inside diameter	Gi		in		in
Basic seating width	b_0		in		in
Gasket factor (Table 2-5.1)	m				
Gasket seating pressure	Y		psi		psi
Diameter of gasket force	G	32.38	in		in
Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Initial gasket force	W		lbf	**0**	lbf
Gasket operation force	W	656000	lbf	**0**	lbf
Total req. bolt root area	A_m		in²	**0**	in²
Flange thickness	h_r		in		in

Bolt area in² :

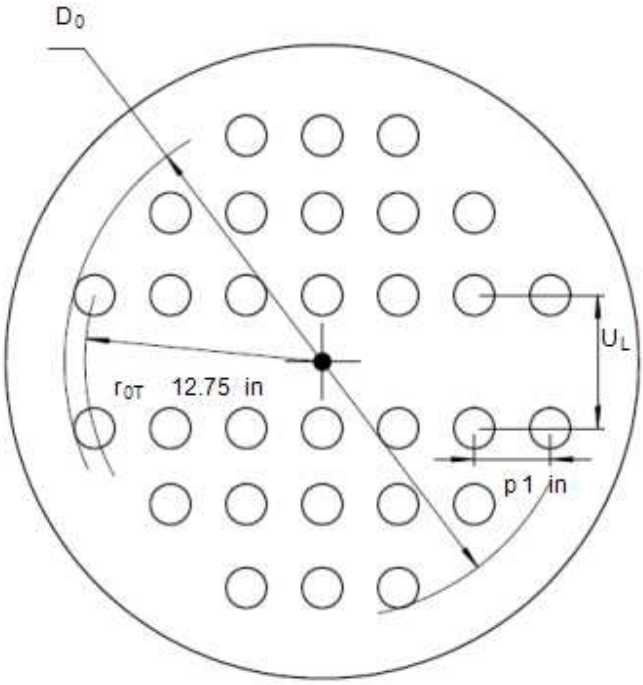
Additional specifications for geometry and loading

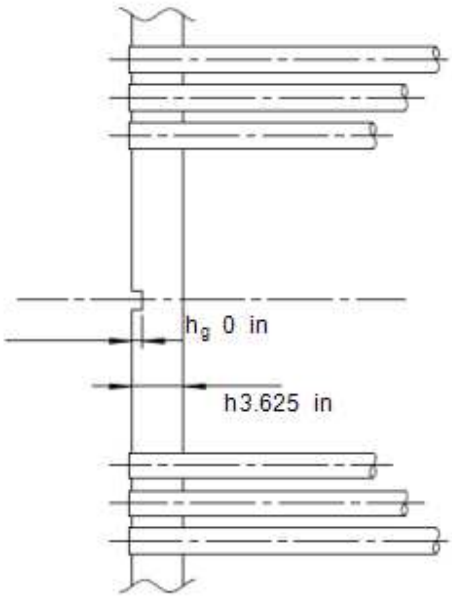
Tubesheet

12.6 Calculation as simply supported tubesheet		N	(Y,N)
Tube joint	(1=expanded, 2=backside-welded)	1	(1, 2)
Tube hole pattern	(1=Triangle, 2=Square)	2	(1, 2)



Expanded length of tube in tubesheet		$l_{t,x}$	**3.5**	in
Radius to outermost tube hole center	UHX-11.1a	r_{0T}	12.75	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by Cp	UHX-12.2	A_p		in²
Tube hole pitch (Center distance)		p	1	in





Untubed area UL1·LL1+UL2·LL2...	UHX-11.2	A_L	36.09	in²
Depth of pass partition groove		h_g	0	in
Length ratio of tube expansion ltx/h		ρ	1	

Results acc. to UHX-12

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	App.2-5	W_m	656000	lbf
Channel thickness without allowances		t_c	**0.625**	in
Shell thickness without allowances		t_s		in
Recommended initial tubesheet thickness	UHX-12.4	h_{in}	**1.066**	in
Tubesheet thickness without allowances > hin		h	**3.5**	in

Step 1 acc. to UHX 12.5

Equivalent diameter of outer tube limit circle	D_0	**26.25**	in
Basic ligament efficiency for shear	μ	**0.25**	
Effective tubeside pass partition groove depth	h_g'	**0**	in

Step 2

Ratio Ds/D0 (Type abc) or Gs/D0 (Type def)	ρ_S	**1.233**	
Ratio Dc/D0 (Type aef) or Gc/D0 (Type bcd)	ρ_C	**1.181**	
Tubesheet rim moment due to P_s and P_t	M_{TS}	**16467**	lbf

Step 3

Effective mod. elasticity tubesheet	UHX-11.2, 11.3	E*	**1.227e+7**	psi
Effective Poisson's ratio of tubesheet		v*	**0.3179**	
Effective tube pitch		p*	**1.035**	in
Effective ligament efficiency for bending		μ*	**0.3854**	
Effective tube hole diameter		d*	**0.6362**	in

Step 4

Coefficient for moment of shell	ω_S	**0**	in²
Coefficient for moment of channel	ω_C	**7.013**	in²

Step 5

Diameter ratio = A/D0	K	**1.419**	
Coefficient	F	**0.9647**	

Step 6

Rim moment	M*	**26908**	lbf

Step 7

Bending moment at periphery	M_p	**6823**	lbf
Moment at the tubesheet center	M_0	**30043**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **38180** psi < **40030** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **4875** psi < **16012** psi = $0.8 \cdot \sigma_B$

Strength condition satisfied

Step 10: Absolute values of stress σS in the shell and und σC in the channel

σ_S = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ = **0** psi + **0** psi

σ_C = **56960** psi < **30023** psi = $1.5 \cdot \sigma_{all}$

$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ = **0** psi + **-56960** psi

Shell length, uniform thickness > l_{Sm} = 0 or in

Channel length, uniform thickness > l_{Cm} = 0 or **7.923** in

Stress too high, increase tubesheet or channel thickness UHX-12.5.10

Step 11 option 3: If the strength condition of step 10 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 allows also the reduction of the elastic modulus of the shell and/or the channel.

Geometric conditions:

valid

Equations acc. to UHX-12.5 (in SI-Units)

12.4(c) If: Tubesheet thickness = 3.625 in < 0.75 in
= Tube outside diameter, the tube sheet deflection should be considered

Allowable primary and secondary stress in the shell acc. to UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2·Yield strength (b) for operation
0 psi = 3· 0 psi or 2· psi
(b) under the condition: σ_{all} not in the creep range
T= 400 °F < °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.159\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.159\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 92.07\ \text{mm} - 0\ \text{mm} - 3.175\ \text{mm} = 88.9\ \text{mm}$$

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot |p_T - p_S| =$$

(estimation, deleted Add.2009)

$$\frac{1}{(4 \cdot 0.25)} \cdot \frac{666.8\ \text{mm}}{(0.8 \cdot 138\ \text{N/mm}^2)} \cdot |4.482\ \text{N/mm}^2 - 4.482\ \text{N/mm}^2| = 27.07\ \text{mm}$$

UHX-12.5.1 Step 1

$$D_0 = 2 \cdot r_0 + d_{aT} = 2 \cdot 323.9\ \text{mm} + 19.05\ \text{mm} = 666.8\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(25.4\ \text{mm} - 19.05\ \text{mm})}{25.4\ \text{mm}} = 0.25$$

$$0\ \text{mm} = Max\begin{cases}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{cases}$$

UHX-12.5.2 Step 2

$$M_{TS120} = \frac{D0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S{}^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho C^2 + 1) \cdot P_t\right] =$$

$$\frac{(666.8\ \text{mm})^2}{16} \cdot [((1.233 - 1)((1.233)^2 + 1) \cdot 4.482\ \text{N/mm}^2) - (1.181 - 1)((1.181)^2 + 1) \cdot 4.482\ \text{N/mm}^2] = 73250\ \text{N}$$

UHX-12.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{88.9\ \text{mm}}{88.9\ \text{mm}} = 1$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D0^2}}} = \frac{25.4\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 23286\ \text{mm}^2}{\pi \cdot (666.8\ \text{mm})^2}}} = 26.29\ \text{mm}$$

$$d^* = Max\begin{cases}d1^* \\ d2^*\end{cases}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.159\ \text{mm}) = d1^*$$

$$d2^*=d_T-2\cdot t_T\cdot\frac{E_T}{E_B}\cdot\frac{\sigma_T}{\sigma_B}\cdot\rho=19.05\text{ mm}-2\cdot 2.159\text{ mm}\cdot\frac{191733\text{ N/mm²}}{191734\text{ N/mm²}}\cdot\frac{92.4\text{ N/mm²}}{138\text{ N/mm²}}\cdot 1=d2^*$$

$$\mu^*=\frac{(p^*-d^*)}{d^*}=\frac{(26.29\text{ mm}-16.16\text{ mm})}{16.16\text{ mm}}=0.3854$$

UHX-12.5.4 Step 4

Type abc:	β_S		1/ft	k_S		lbf	λ_S	**0** psi
Type aef:	β_C	**4.907**	1/ft	k_C	**508427**	lbf	λ_C	**7620705** psi

UHX-12.5.5 Step 5

$$F=\frac{(1-v^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.3179)}{84598\text{ N/mm²}}\cdot(0\text{ N/mm²}+52543\text{ N/mm²}+191734\text{ N/mm²}\cdot\ln(1.419))=0.9647$$

UHX-12.5.6 Step 6

$$M^*=M_{TS}+\omega_C\cdot P_c-\omega_S\cdot P_s+M_{add}=73250\text{ N}+4524\text{ mm²}\cdot 0\text{ N/mm²}-0\text{ mm²}\cdot 4.482\text{ N/mm²}+46442\text{ N}=119692\text{ N}$$

M_{add} = (C-Gs)*Wm/(2* PI *D0) = **10441** lbf

UHX-12.5.6 acc. UHX-12.6

$$Mfd^*=M_{TS}+M_{add}=73250\text{ N}+46442\text{ N}=119692\text{ N}$$

Step 8: Strength condition for the bending stress in the tubesheet:

σ			**or**	**σ acc. UHX12.6**		**< 2· σ_B**		
σ =	**38180**	psi	or	**45454**	psi	< 2·	**20015**	psi

Step 9: Strength condition for the shear stress in the tubesheet:

τ			**or**	**τ acc. UHX12.6**		**< 0.8· σ_B**		
τ =	**4875**	psi	or	**4875**	psi	< 0.8·	**20015**	psi

Strength condition satisfied

If the strength condition in step 8 or 9 is violated, the tubesheet thickness must be increased.
Actual thickness 3.625 in

Step 10: Absolute values of stresses σ_S in the shell and σ_C in the channel

in MPa:	**σ_m**		**σ_b**			**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**0**	+	**0**	=	**0**	< 1.5·	0	or	0
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**0**	+	**-392.7**	=	**392.7**	< 1.5·	**138**	or	**448.6**

*) Simply supported (N) acc. UHX-12.6

Stress too high, increase tubesheet or channel thickness UHX-12.5.10

Step 11: The modulus of elasticity is reduced: N (Y=Yes,N=No)

Modulus of elasticity	elastic	Option 3
Shell	**0** psi	**0** psi
Channel	**2.781e+7** psi	**2.781e+7** psi

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S\cdot\sqrt{(1.5\cdot\sigma_{allS}/\sigma_S)}$, under the conditions:

σ_S = **0** psi ≤ 0 psi = S_{PSs}

with the allowable primary+secondary stress S_{PSs}, if the allowable stress σ_{allS} is outside of the creep range!

Analogously for the channel:

σ_C = **56960** psi ≤ **65060** psi = S_{PSc}

E4.18.4 (elastic-plastic)
ASME UHX-12 U-Tubesheets ASME BPVC Edition 2017

U-Tubesheet Heat Exchanger according to ASME-UHX-12

Configuration of the tubesheet (a, b, ..., f)		Type e		(a-f)
Tubesheet with flange, gasketed with shell, integral with channel				
Channel type (1=Cylinder, 2=Hemispherical)			1	(1,2)
Internal operation pressure shell side		P_s	650	psi
Internal operation pressure tube side		P_t	650	psi
Internal test pressure shell side		P_{sp}	845.1	psi
Internal test pressure tube side		P_{tp}	845.1	psi
Load case	(1=Operation, 2+3=Test at 20°C, 4=other)		1	
load case: operation				
Calculation case UHX12.4(a) (1: Ps=0, 2: Pt=0, 3:Differ.)			2	(1-3)
Shell side pressure acting (Pt=0)				
Material tubesheet	K02700-SA-516-70-Class:-Size:			
Material shell (Type abc)				
Material tubes	K01200-SA-179--Class:-Size:			
Mat. channel (Type aef)	K02700-SA-516-70-Class:-Size:			

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	400	°F		°F	400	°F	400	°F
Thickness	3.625	in		in	0.085	in	0.625	in
Outside diameter	37.25	in		in	0.75	in	32.25	in
Strength	20015	psi		psi	13401	psi	20015	psi
Safety fac.	1				1		1	
E-module	2.781e+7	psi	0	psi	2.781e+7	psi	2.781e+7	psi
Allow. c_1	0	in		in	0	in	0	in
Corr.all. c_2	0.125	in		in	0	in	0	in
Poisson's ratio		v	0.3				0.3	
Therm.exp.	7.07	1E-6/°F		1E-6/°F	7.07	1E-6/°F	7.07	1E-6/°F
Yield str.	32530	psi		psi	22258	psi	32530	psi
Limit temperature	752	°F		°F	752	°F	752	°F
All.Stress	**20015**	psi	0	psi	**13401**	psi	**20015**	psi
Pr.+sec.st	**65060**	psi	0	psi	**44517**	psi	**65060**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	33939	psi	0	psi	23496	psi	33939	psi
Safety fac.	1				1		1	
E-module	2.93e+7	psi		psi	2.93e+7	psi	2.93e+7	psi
Yield str.	37710	psi		psi	26107	psi	37710	psi
Tensile str.	70343	psi		psi	47137	psi	70343	psi

Mean contact diameter tubesheet-flange (Type cf)	G_1		in
Bolt circle diameter (Type bcdef)	C	35	in
Number of bolts	n		-
Bolt root diameter	d_B		in
Total bolt area	A_b		in²
Bolt material			
Strength for operation	K_s		psi
Strength at 20°C (or test)	K_{sp}		psi
Safety for operation	S_s		-
Safety at 20°C (or test)	S_{sp}		-
Stress enhancement factor acc. App. S	F_s	1.5	-
Allowable testing stress for bolts	σ		psi
Yield stress (20°C)	Rp0,2RT		psi
Flange material			
Strength operation	K_f		psi
Strength at 20°C (or test)	K_{fp}		psi
Safety for operation	S_f		-
Safety at 20°C (or test)	S_{fp}		-

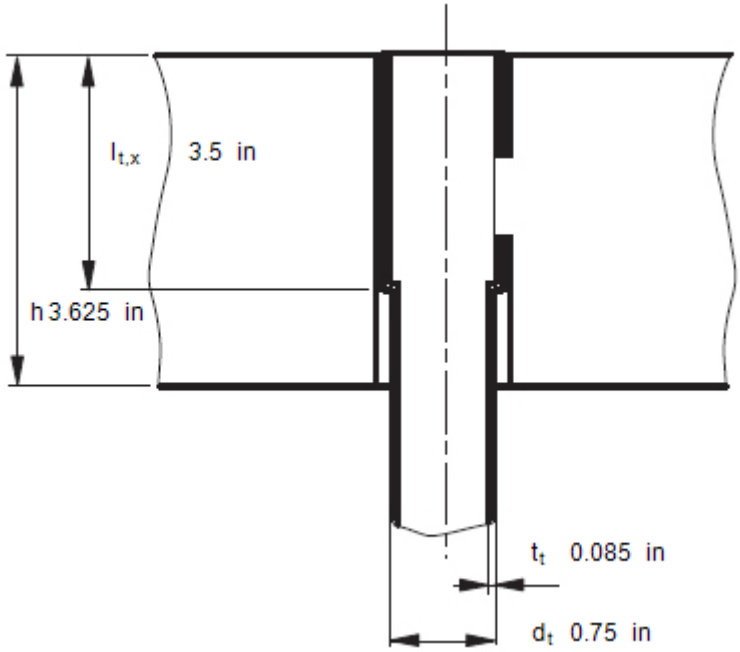
		Shell		Channel	
Gasket		**Type d,e,f**		**Type b,c,d**	
Contact outside diameter	G_a		in		in
Contact inside diameter	Gi		in		in
Basic seating width	b_0		in		in
Gasket factor (Table 2-5.1)	m				
Gasket seating pressure	Y		psi		psi
Diameter of gasket force	G	32.38	in		in
Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Initial gasket force	W		lbf	**0**	lbf
Gasket operation force	W	656000	lbf	**0**	lbf
Total req. bolt root area	A_m		in²	**0**	in²
Flange thickness	h_r		in		in

Bolt area in² :

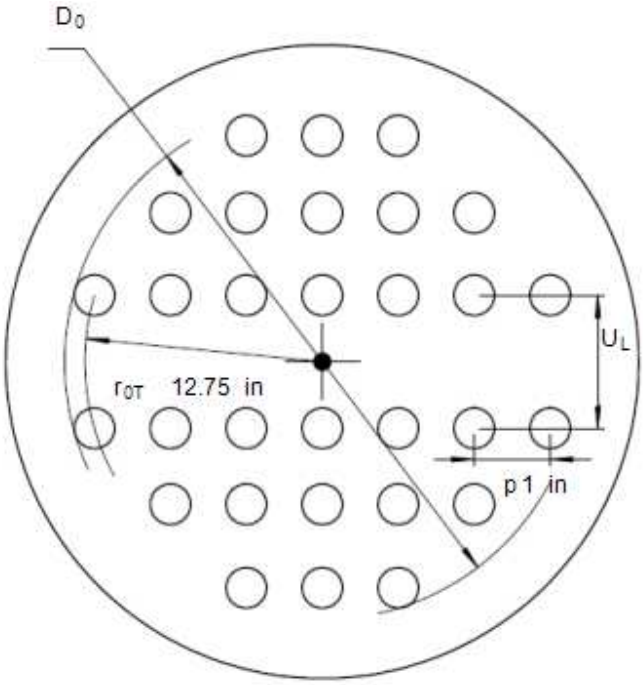
Additional specifications for geometry and loading

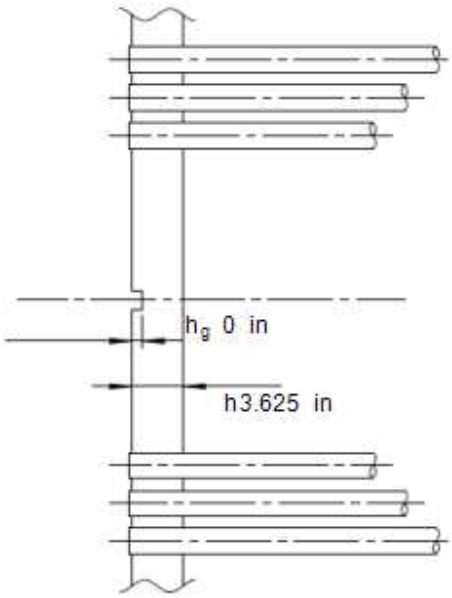
Tubesheet

12.6 Calculation as simply supported tubesheet		N	(Y,N)
Tube joint	(1=expanded, 2=backside-welded)	1	(1, 2)
Tube hole pattern	(1=Triangle, 2=Square)	2	(1, 2)



Expanded length of tube in tubesheet		$l_{t,x}$	**3.5**	in
Radius to outermost tube hole center	UHX-11.1a	r_{0T}	12.75	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by Cp	UHX-12.2	A_p		in²
Tube hole pitch (Center distance)		p	1	in





Untubed area UL1·LL1+UL2·LL2...	UHX-11.2	A_L	36.09	in²
Depth of pass partition groove		h_g	0	in
Length ratio of tube expansion ltx/h		ρ	1	

Results acc. to UHX-12

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	App.2-5	W_m	656000	lbf
Channel thickness without allowances		t_c	**0.625**	in
Shell thickness without allowances		t_s		in
Recommended initial tubesheet thickness	UHX-12.4	h_{in}	**1.066**	in
Tubesheet thickness without allowances > hin		h	**3.5**	in

Step 1 acc. to UHX 12.5

Equivalent diameter of outer tube limit circle		D_0	**26.25**	in
Basic ligament efficiency for shear		μ	**0.25**	
Effective tubeside pass partition groove depth		h_g'	**0**	in

Step 2

Ratio Ds/D0 (Type abc) or Gs/D0 (Type def)		ρ_S	**1.233**	
Ratio Dc/D0 (Type aef) or Gc/D0 (Type bcd)		ρ_C	**1.181**	
Tubesheet rim moment due to P_s and P_t		M_{TS}	**16467**	lbf

Step 3

Effective mod. elasticity tubesheet	UHX-11.2, 11.3	E*	**1.227e+7**	psi
Effective Poisson's ratio of tubesheet		v*	**0.3179**	
Effective tube pitch		p*	**1.035**	in
Effective ligament efficiency for bending		μ*	**0.3854**	
Effective tube hole diameter		d*	**0.6362**	in

Step 4

Coefficient for moment of shell	ω_S	**0**	in²
Coefficient for moment of channel	ω_C	**7.013**	in²

Step 5

Diameter ratio = A/D0	K	**1.419**	
Coefficient	F	**0.8486**	

Step 6

Rim moment	M*	**26908**	lbf

Step 7

Bending moment at periphery	M_p	**8130**	lbf
Moment at the tubesheet center	M_0	**31350**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **39842** psi < **40030** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **4875** psi < **16012** psi = $0.8 \cdot \sigma_B$

Strength condition satisfied

Step 10: Absolute values of stress σS in the shell and und σC in the channel

σ_S = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ = **0** psi + **0** psi

σ_C = **43952** psi < **30023** psi = $1.5 \cdot \sigma_{all}$

$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ = **0** psi + **-43952** psi

Shell length, uniform thickness > l_{Sm} = 0	or		in
Channel length, uniform thickness > l_{Cm} = 0	or	**7.923**	in

UHX-12.5.10 Step 10 is not required using option 3

Step 11 option 3: If the strength condition of step 10 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 allows also the reduction of the elastic modulus of the shell and/or the channel.

Geometric conditions:

valid

Equations acc. to UHX-12.5 (in SI-Units)

12.4(c) If: Tubesheet thickness = 3.625 in < 0.75 in
= Tube outside diameter, the tube sheet deflection should be considered

Allowable primary and secondary stress in the shell acc. to UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2·Yield strength (b) for operation
0 psi = 3· 0 psi or 2· psi
(b) under the condition: σ_{all} not in the creep range
T= 400 °F < °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.159\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.159\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 92.07\ \text{mm} - 0\ \text{mm} - 3.175\ \text{mm} = 88.9\ \text{mm}$$

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot |p_T - p_S| =$$

(estimation, deleted Add.2009)

$$\frac{1}{(4 \cdot 0.25)} \cdot \frac{666.8\ \text{mm}}{(0.8 \cdot 138\ \text{N/mm}^2)} \cdot |4.482\ \text{N/mm}^2 - 4.482\ \text{N/mm}^2| = 27.07\ \text{mm}$$

UHX-12.5.1 Step 1

$$D_0 = 2 \cdot r_0 + d_{aT} = 2 \cdot 323.9\ \text{mm} + 19.05\ \text{mm} = 666.8\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(25.4\ \text{mm} - 19.05\ \text{mm})}{25.4\ \text{mm}} = 0.25$$

$$0\ \text{mm} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix}$$

UHX-12.5.2 Step 2

$$M_{TS120} = \frac{D0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S{}^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho C^2 + 1) \cdot P_t\right] =$$

$$\frac{(666.8\ \text{mm})^2}{16} \cdot [((1.233 - 1)((1.233)^2 + 1) \cdot 4.482\ \text{N/mm}^2) - (1.181 - 1)((1.181)^2 + 1) \cdot 4.482\ \text{N/mm}^2] = 73250\ \text{N}$$

UHX-12.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{88.9\ \text{mm}}{88.9\ \text{mm}} = 1$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D0^2}}} = \frac{25.4\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 23286\ \text{mm}^2}{\pi \cdot (666.8\ \text{mm})^2}}} = 26.29\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d1^* \\ d2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.159\ \text{mm}) = d1^*$$

$$d2^*=d_T-2\cdot t_T\cdot\frac{E_T}{E_B}\cdot\frac{\sigma_T}{\sigma_B}\cdot\rho=19.05\text{ mm}-2\cdot 2.159\text{ mm}\cdot\frac{191733\text{ N/mm²}}{191733\text{ N/mm²}}\cdot\frac{92.4\text{ N/mm²}}{138\text{ N/mm²}}\cdot 1=d2^*$$

$$\mu^*=\frac{(p^*-d^*)}{d^*}=\frac{(26.29\text{ mm}-16.16\text{ mm})}{16.16\text{ mm}}=0.3854$$

UHX-12.5.4 Step 4

Type abc:	β_S		1/ft	k_S		lbf	λ_S	**0** psi
Type aef:	β_C	**4.907**	1/ft	k_C	**369139**	lbf	λ_C	**5532951** psi

UHX-12.5.5 Step 5

$$F=\frac{(1-v^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.3179)}{84598\text{ N/mm²}}\cdot(0\text{ N/mm²}+38149\text{ N/mm²}+191733\text{ N/mm²}\cdot\ln(1.419))=0.8486$$

UHX-12.5.6 Step 6

$$M^*=M_{TS}+\omega_C\cdot P_c-\omega_S\cdot P_s+M_{add}=73250\text{ N}+4524\text{ mm²}\cdot 0\text{ N/mm²}-0\text{ mm²}\cdot 4.482\text{ N/mm²}+46442\text{ N}=119692\text{ N}$$

M_{add} = (C-Gs)*Wm/(2* PI *D0) = **10441** lbf

UHX-12.5.6 acc. UHX-12.6

$$Mfd^*=M_{TS}+M_{add}=73250\text{ N}+46442\text{ N}=119692\text{ N}$$

Step 8: Strength condition for the bending stress in the tubesheet:

σ			**or**	**σ acc. UHX12.6**		**< 2· σ_B**		
σ =	**39842**	psi	or	**45454**	psi	< 2·	**20015**	psi

Step 9: Strength condition for the shear stress in the tubesheet:

τ			**or**	**τ acc. UHX12.6**		**< 0.8· σ_B**		
τ =	**4875**	psi	or	**4875**	psi	< 0.8·	**20015**	psi

Strength condition satisfied

If the strength condition in step 8 or 9 is violated, the tubesheet thickness must be increased.
Actual thickness 3.625 in

Step 10: Absolute values of stresses σ_S in the shell and σ_C in the channel

in MPa:	**σ_m**		**σ_b**			**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**0**	+	**0**	=	**0**	< 1.5·	0	or	0
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**0**	+	**-303**	=	**303**	< 1.5·	**138**	or	**448.6**

*) Simply supported (N) acc. UHX-12.6

UHX-12.5.10 Step 10 is not required using option 3

Step 11: The modulus of elasticity is reduced: j (Y=Yes,N=No)

Modulus of elasticity	elastic	Option 3
Shell	**0** psi	**0** psi
Channel	**2.781e+7** psi	**2.019e+7** psi

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S\cdot\sqrt{(1.5\cdot\sigma_{allS}/\sigma_S)}$, under the conditions:

σ_S = **0** psi ≤ 0 psi = S_{PSs}

with the allowable primary+secondary stress S_{PSs}, if the allowable stress σ_{allS} is outside of the creep range!

Analogously for the channel:

σ_C = **43952** psi ≤ **65060** psi = S_{PSc}

7 Table E4.18.1
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.1 and LV calculation arranged in 3 lines.
Line 1: LV, line 2 = ASME, line 3 = difference %.

	Conversion factors		Step 1-3		Maximum			
	MPa2psi	N2lb	mm2in	my*	MTS	ny*	E*	diff.%
1	145	0.2248	0.03937	0.349	-160.4	0.2539	1.152e+7	
2	0	0	0	0.349	-160	0.254	1.15e+7	
3	0	0	0	-6.85e-3	0.223	-0.02657	0.1477	0.223
---- Step 4 ----								
	betaS	ks	lambdaS	deltaS	omegaS			:MaxDif%
4	1.209	33399	3.208e+7	7.004e-6	0.491			
5	1.21	33300	3.2e+7	7.02e-6	0.491			
6	-0.1226	0.2977	0.2631	-0.2229	0.001324	0	0	0.2977
---- Step 4 ----								
	betaC	kC	lambdaC	deltaC	omegaC			:MaxDif%
7	0.9144	132872	1.103e+8	3.979e-6	0.7559			
8	0.914	132000	1.1e+8	3.99e-6	0.756			
9	0.04329	0.6604	0.3101	-0.2808	-7.1e-3	0	0	0.6604
---- Step 6-9 ----								
	M*:	Mp	M0	Sig	Tau			:MaxDif%
10	-49.62	567.9	-462.9	35963	3346			
11	-49.4	568	-463	36000	3350			
12	0.4404	-0.01667	-0.02711	-0.1018	-0.1085	0	0	0.4404
---- Step 10 ----								
	SigSm	SigSb	SigS	SigCm	SigCb	SigC		:MaxDiff%
13	-169.6	-17576	17745	1342	25272	26615		
14	-170	-17600	17700	1340	25300	26600		
15	-0.2494	-0.1376	0.2563	0.1859	-0.1105	0.05459	0	0.2563

Differences for actual and previous 2010-02-11 calculation

16	0.223	0.2977	0.6604	0.4404	0.2563			
17	0.223	0.2977	0.6604	0.4404	0.2563			
18	0	0	0	0	0	0	0	0
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

8 Table E4.18.2
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.2 and LV calculation arranged in 3 lines.
Line 1: LV, line 2 = ASME, line 3 = difference %.

	Conversion factors		Step 1-3		Maximum			
	MPa2psi	N2lb	mm2in	my*	MTS	ny*	E*	diff.%
1	145	0.2248	0.03937	0.2798	-784.9	0.3576	7501671	
2	0	0	0	0.28	-785	0.358	7500000	
3	0	0	0	-0.06139	-9.5e-3	-0.1174	0.02228	0.1174

---- Step 4 ----

	betaS	ks	lambdaS	deltaS	omegaS			:MaxDif%
4	0	0	0	0	0			
5	0	0	0	0	0			
6	0	0	0	0	0	0	0	0

---- Step 4 ----

	betaC	kC	lambdaC	deltaC	omegaC			:MaxDif%
7	0	0	0	0	0			
8	0	0	0	0	0			
9	0	0	0	0	0	0	0	0

---- Step 6-9 ----

	M*:	Mp	M0	Sig	Tau			:MaxDif%
10	-784.9	-160.4	-2385	-31203	2955			
11	-785	-160	-2380	31200	2960			
12	-9.5e-3	0.2463	0.2016	0.009487	-0.1804	0	0	0.2463

---- Step 10 ----

	SigSm	SigSb	SigS	SigCm	SigCb	SigC	:MaxDiff%			
13	0	0	0	0	0	0	0			
14	0	0	0	0	0	0	0			
15	0	0	0	0	0	0	0	0	0	0

Differences for actual and previous 2010-02-11 calculation

16	0.1174	0	0	0.2463	0			
17	0.1174	0	0	0.2463	0			
18	0	0	0	0	0	0	0	0
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

9 Table E4.18.3
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.3 and LV calculation arranged in 3 lines.
Line 1: LV, line 2 = ASME, line 3 = difference %.

	Conversion factors		Step 1-3		Maximum			
	MPa2psi	N2lb	mm2in	my*	MTS	ny*	E*	diff.%
1	145	0.2248	0.03937	0.2401	2251	0.407	5572629	
2	0	0	0	0.24	2250	0.407	5540000	
3	0	0	0	0.0595	0.04	0.005848	0.589	0.589

---- Step 4 ----

	betaS	ks	lambdaS	deltaS	omegaS			MaxDif%
4	0	0	0	0	0			
5	0	0	0	0	0			
6	0	0	0	0	0	0	0	0

---- Step 4 ----

	betaC	kC	lambdaC	deltaC	omegaC			MaxDif%
7	0	0	0	0	0			
8	0	0	0	0	0			
9	0	0	0	0	0	0	0	0

---- Step 6-9 ----

	M*	Mp	M0	Sig	Tau			MaxDif%
10	5802	-1152	26684	39896	3772			
11	5800	-1150	26700	39900	3770			
12	0.02945	0.187	-0.05854	-0.0105	0.04326	0	0	0.187

---- Step 10 ----

	SigSm	SigSb	SigS	SigCm	SigCb	SigC		MaxDiff%
13	0	0	0	0	0	0		
14	0	0	0	0	0	0		
15	0	0	0	0	0	0	0	0

Differences for actual and previous 2010-02-11 calculation

16	0.589	0	0	0.187	0			
17	0.589	0	0	0.187	0			
18	0	0	0	0	0	0	0	0
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

10 Table E4.18.4
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.4 and LV calculation arranged in 3 lines.
Line 1: LV, line 2 = ASME, line 3 = difference %.

	Conversion factors		Step 1-3		Maximum			
:	MPa2psi :	N2lb :	mm2in :	my* :	MTS :	ny* :	E*	: diff.%
1	145	0.2248	0.03937	0.3854	16467	0.3179	1.227e+7	
2	0	0	0	0.385	16500	0.318	1.22e+7	
3	0	0	0	0.1055	-0.2019	-0.02572	0.5464	0.5464

---- Step 4 ----

:	betaS :	ks :	lambdaS :	deltaS :	omegaS :			: MaxDif%
4	0	0	0	0	0			
5	0	0	0	0	0			
6	0	0	0	0	0	0	0	0

---- Step 4 ----

:	betaC :	kC :	lambdaC :	deltaC :	omegaC :		:	MaxDif%
7	0.4089	508404	7618761	1.175e-5	7.013			
8	0.409	506000	7590000	1.18e-5	7.01			
9	-0.02814	0.4752	0.3789	-0.4236	0.03802	0	0	0.4752

---- Step 6-9 ----

:	M*:	Mp :	M0 :	Sig :	Tau :			:MaxDif%
10	26907	6823	30042	38171	4874			
11	26900	6830	30000	38200	4880			
12	0.0252	-0.1016	0.1401	-0.0767	-0.1278	0	0	0.1401

---- Step 10 ----

:	SigSm :	SigSb :	SigS :	SigCm :	SigCb :	SigC :		:MaxDiff%
13	0	0	0	0	-56946	56946		
14	0	0	0	0	-57000	57000		
15	0	0	0	0	-0.09509	-0.09509	0	0.09509

Differences for actual and previous 2010-02-11 calculation

16	0.5464	0	0.4752	0.1401	0.09509			
17	0.5463	0	0.4752	0.1401	0.095			
18	0.01501	0	0	0	0.09234	0	0	0.09234
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

Links

1 4 UHXa: MPa2psi = 145: N2lb = 0.2248: mm2in=0.03937: #88: #120*N2lb: #100: #98*MPa2psi
2 10 EQU: :::0.385: 16500:0.318:12.2E+6
3 10 EQU: :::(|#143|-|#151|)/|#151|*100:(|#144|-|#152|)/|#152|*100:(|#145|-|#153|)/|#153|*100:(|#146|-|#154|)/|#154|*100:Max(|#1
4 4 UHXa: #121/mm2in: #122*N2lb: #123*MPa2psi: #124*mm2in^3/N2lb: #125*mm2in^2
5 10 EQU:::::
6
7 4 UHXa: #126/mm2in: #127*N2lb: #128*MPa2psi: #129*mm2in^3/N2lb: #130*mm2in^2
8 10 EQU:0.409:506000:7.59E6:1.18E-5:7.01
9
10 4 UHXa: N2lb*#134: N2lb*#135: N2lb*#136: MPa2psi*#138: MPa2psi*#140
11 10 EQU: 26900: 6830: 30000: 38200: 4880
12
13 4 UHXa: MPa2psi*#142: MPa2psi*#143: MPa2psi*#144: MPa2psi*#146: MPa2psi*#147: MPa2psi*#148
14 10 EQU::::0:-57000:57000
15

16 10 actual EQU: #163: #187: #211: #235: #259
17 '10 previous EQU: #163: #187: #211: #235: #259
18
19
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21
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30

Additional comments

Units		**Value**	**Unit**		**Selected Unit**
Conversion	#121=			= #123 =	

11 Table E4.18.4 (elastic-plastic)
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.4(plastic) and LV calculation arranged
in 3 lines. Line 1: LV, line 2 = ASME, line 3 = difference %.

	Conversion factors		Step 1-3		Maximum			
	MPa2psi	N2lb	mm2in	my*	MTS	ny*	E*	Diff.%
1	145	0.2248	0.03937	0.3854	16467	0.3179	1.227e+7	
2	0	0	0	0.385	16500	0.318	1.22e+7	
3	0	0	0	0.1056	-0.2019	-0.02572	0.5463	0.5463

---- Step 4 ----

	betaS	ks	lambdaS	deltaS	omegaS			:MaxDif%
4	0	0	0	0	0			
5	0	0	0	0	0			
6	0	0	0	0	0	0	0	0

---- Step 4 ----

	betaC	kC	lambdaC	deltaC	omegaC			:MaxDif%
7	0.4089	369123	5531540	1.618e-5	7.013			
8	0.409	368000	5510000	1.62e-5	7.01			
9	-0.02814	0.3051	0.3909	-0.1009	0.03802	0	0	0.3909

---- Step 6-9 ----

	M*:	Mp	M0	Sig	Tau			:MaxDif%
10	26907	8130	31349	39831	4874			
11	26900	8130	31400	39800	4880			
12	0.0252	0.001415	-0.1621	0.07889	-0.1278	0	0	0.1621

Differences for actual and previous 2010-02-11 calculation

13	0.5463	0	0.3909	0.1621	0.01501			
14	0.5464	0	0.3909	0.1621	0			
15	-0.01501	0	0	0	0	0	0	0.01501

Links

1 5 UHXa: MPa2psi = 145: N2lb = 0.2248: mm2in=0.03937: #88: #120*N2lb: #100: #98*MPa2psi
2 11 EQU: :::0.385: 16500:0.318:12.2E+6
3 11 EQU: :::(|#143|-|#151|)/|#151|*100:(|#144|-|#152|)/|#152|*100:(|#145|-|#153|)/|#153|*100:(|#146|-|#154|)/|#154|*100:Max(|#1
4 5 UHXa: #121/mm2in: #122*N2lb: #123*MPa2psi: #124*mm2in^3/N2lb: #125*mm2in^2
5 11 EQU:::::
6
7 5 UHXa: #126/mm2in: #127*N2lb: #128*MPa2psi: #129*mm2in^3/N2lb: #130*mm2in^2
8 11 EQU:0.409:368000:5.51E6:1.62E-5:7.01
9
10 5 UHXa: N2lb*#134: N2lb*#135: N2lb*#136: MPa2psi*#138: MPa2psi*#140
11 11 EQU: 26900: 8130: 31400: 39800: 4880
12
13 11 actual EQU: #163: #187: #211: #235: #259
14 '11 previous EQU: #163: #187: #211: #235: #259
15

Appendix: Material documentation

Section 2: Boden/UHXa
Section 2: Vorkammer/UHXa
Section 2: Boden-Zeitst/UHXa
Section 2: Vorkammer-Zeitst/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-240 Product: Plate
Material code: S31600-SA-240-316-Class:-Size: Short name: 16Cr-12Ni-2Mo

Design conditions and dimensions:

Temperature [°C]: 260 Pressure [bar]: 0
Thickness [mm]: 13,23 Outside diameter [mm]: 328,68

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	124,60
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	124,60
Modulus of elasticity [kN/mm²]:	195	178,4

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
	138	138	134	126	119	114	111	

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
	108	107	105	80.3	50.4	29.6	10.4

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

650	-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
146	201	209	204	195	189	186	183	179	176	172	169	165	160	156

Static modulus of elasticity in [kN/mm²] at the temperature of

600	700
151	140

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7,85	16,2	17,0	17,7	18,1	18,6					

Section 2: Mantel/UHXa
Section 2: Mantel-Zeitst/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-312 Product: Smls. & wld. pipe
Material code: S31600-SA-312-TP316-Class:-Size: Short name: 16Cr-12Ni-2Mo

Design conditions and dimensions:

Temperature [°C]: 260 Pressure [bar]: 0
Thickness [mm]: 4,57 Outside diameter [mm]: 323,85

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	124,60
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	124,60
Modulus of elasticity [kN/mm²]:	195	178,4

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		138	138	134	126	119	114	111

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
	108	107	105	80.3	50.4	29.6	10.4

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

650	-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
146	201	209	204	195	189	186	183	179	176	172	169	165	160	156

Static modulus of elasticity in [kN/mm²] at the temperature of

600	700
151	140

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK

7,85···|16,2···|17,0···|17,7···|18,1···|18,6···|·······|·······|·······|·······|·······

Section 2: Rohre/UHXa
Section 2: Rohre-Zeitst/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-213 Product: Smls. tube
Material code: S31600-SA-213-TP316-Class:-Size: Short name: 16Cr-12Ni-2Mo

Design conditions and dimensions:

Temperature [°C]: 260 Pressure [bar]: 0
Thickness [mm]: 1,65 Outside diameter [mm]: 19,05

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	124,60
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	124,60
Modulus of elasticity [kN/mm²]:	195	178,4

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %
...	...	...	...	...	...

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
...	...	138	138	134	126	119	114	111

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
...	108	107	105	80.3	50.4	29.6	10.4

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

650	-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
146	201	209	204	195	189	186	183	179	176	172	169	165	160	156

Static modulus of elasticity in [kN/mm²] at the temperature of

600	700			
151	140			

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK

7,85···|16,2···|17,0···|17,7···|18,1···|18,6···|·------·|·------·|·------·|·------·|·------·

Section 3: Boden/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-285 Product: Plate
Material code: K02801-SA-285-C-Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 148,89 Pressure [bar]: 0
Thickness [mm]: 35,69 Outside diameter [mm]: 508

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	108,00	108,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	108,00	108,00
Modulus of elasticity [kN/mm²]:	202	195,0666

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
	108	108	108	108	107	101	89.1	

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
	62.6	31.6					

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
209	216	212	202	198	195	192	189	185	179	171	162	151	137

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7,85	12,1	12,7	13,3	13,8	14,4					

Section 3: Rohre/UHXa
Section 3: Rohre-Zeitst/UHXa

Material specification:

Regulation: ASMET1B:2013Spec. No.: SB-111 Product: Smls. cond. tube
Material code: C44300-SB-111--Class:O61-Size:<75 Short name:

Design conditions and dimensions:

Temperature [°C]: 148,8889 Pressure [bar]: 0
Thickness [mm]: 1,65 Outside diameter [mm]: 15,88

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	68,90	68,90
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	68,90	68,90
Modulus of elasticity [kN/mm²]:	110	106,0444

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		68.9	68.9	29.4	9.10			

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200
113	116	115	110	108	106	104

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
8,53	17,6	18,4	19,2	19,8						

Section 3: Boden-Zeitst/UHXa
Section 3: Flange extension/Flanschwerweiterung/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-285 Product: Plate
Material code: K02801-SA-285-C-Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 148,8889 Pressure [bar]: 0
Thickness [mm]: 35,69 Outside diameter [mm]: 508

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	108,00	108,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	108,00	108,00
Modulus of elasticity [kN/mm²]:	202	195,0667

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		108	108	108	108	107	101	89.1

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
	62.6	31.6					

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
209	216	212	202	198	195	192	189	185	179	171	162	151	137

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7,85	12,1	12,7	13,3	13,8	14,4					

Section 3: Bolts/Schrauben/UHXa

Material specification:

Regulation: ASMET3:2010Spec. No.: SA-193 Product: Bolting
Material code: K50100-SA-193-B5-Class:-Size:<=100 Short name: 5Cr-0.5Mo

Design conditions and dimensions:

Temperature [°C]: 148,8889 Pressure [bar]: 0
Thickness [mm]: 2 Outside diameter [mm]: 0

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	138,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	138,00
Modulus of elasticity [kN/mm²]:	213	205,0667

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %
...	...	...	...	...	...

K-values as function of the temperature

Diam./Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
...	...	138	138	138	138	138	138	138

K-values as function of the temperature

Diam./Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
...	105	58.5	33.9	19.5	8.79	...	...

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

650	-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
161	220	228	223	213	208	205	201	198	195	191	187	183	179	174

Static modulus of elasticity in [kN/mm²] at the temperature of

600	700			
168	153	...	...	...

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7,85	12,1	12,6	12,8	13,1	13,4	...	...	...	...	...

Section 4: Boden/UHXa
Section 4: Boden-Zeitst/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-516 Product: Plate
Material code: K02700-SA-516-70-Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 260 Pressure [bar]: 0
Thickness [mm]: 108,59 Outside diameter [mm]: 1241,55

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	137,60
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	137,60
Modulus of elasticity [kN/mm²]:	202	188,2

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %
...	...	...	...	...	...

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
...	...	138	138	138	138	136	128	101

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
...	67.1	33.6	12.9	...	...	...	...

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
209	216	212	202	198	195	192	189	185	179	171	162	151	137

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7,85	12,1	12,7	13,3	13,8	14,4	...	...	...	...	...

Section 4: Rohre/UHXa
Section 4: Rohre-Zeitst/UHXa

Material specification:

Regulation: ASMET1B:2013Spec. No.: SB-111 Product: Smls. tube
Material code: C70600-SB-111--Class:H55-Size: Short name:

Design conditions and dimensions:

Temperature [°C]: 260 Pressure [bar]: 0
Thickness [mm]: 1,24 Outside diameter [mm]: 19,05

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	68,90	54,76
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	68,90	54,76
Modulus of elasticity [kN/mm²]:	124	0

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		65.2	62.0	60.1	56.8	45.2		

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200
127	131	129	124	121	119	117

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
8,94										

Section 5: Boden/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-516 Product: Plate
Material code: K02700-SA-516-70-Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 204,44 Pressure [bar]: 0
Thickness [mm]: 92,07 Outside diameter [mm]: 946,15

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	138,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	138,00
Modulus of elasticity [kN/mm²]:	202	191,7336

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %
...	...	...	...	...	...

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
...	...	138	138	138	138	136	128	101

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
...	67.1	33.6	12.9	...	...	...	...

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
209	216	212	202	198	195	192	189	185	179	171	162	151	137

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7,85	12,1	12,7	13,3	13,8	14,4	...	...	...	...	...

Section 5: Rohre/UHXa
Section 5: Rohre-Zeitst/UHXa
Section 6: Rohre/UHXa
Section 6: Rohre-Zeitst/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-179 Product: Smls. tube
Material code: K01200-SA-179--Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 204,4444 Pressure [bar]: 0
Thickness [mm]: 2,16 Outside diameter [mm]: 19,05

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	92,40	92,40
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	92,40	92,40
Modulus of elasticity [kN/mm²]:	202	191,7333

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		92.4	92.4	92.4	92.4	91.9	87.8	73.3

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
	56.2	31.9					

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
209	216	212	202	198	195	192	189	185	179	171	162	151	137

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7,85	12,1	12,7	13,3	13,8	14,4					

Section 5: Vorkammer/UHXa
Section 5: Boden-Zeitst/UHXa
Section 5: Vorkammer-Zeitst/UHXa
Section 6: Boden/UHXa
Section 6: Vorkammer/UHXa
Section 6: Boden-Zeitst/UHXa
Section 6: Vorkammer-Zeitst/UHXa

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-516 Product: Plate
Material code: K02700-SA-516-70-Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 204,4444 Pressure [bar]: 0
Thickness [mm]: 15,88 Outside diameter [mm]: 819,15

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	138,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	138,00
Modulus of elasticity [kN/mm²]:	202	191,7333

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

Diam./ Thick. <= mm	Tensile str. Rm min MPa	Rm max MPa	ReH MPa	Rupture elong. längs %	Rupture elong quer %
...	...	...	...	...	...

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
...	...	138	138	138	138	136	128	101

K-values as function of the temperature

Diam./ Thickn. <= mm	450°C MPa	500°C MPa	550°C MPa	600°C MPa	650°C MPa	700°C MPa	800°C MPa
...	67.1	33.6	12.9	...	...	...	...

Modulus of elasticity in dependence of the temperature:

Static modulus of elasticity in [kN/mm²] at the temperature of

-75	-200	-125	25	100	150	200	250	300	350	400	450	500	550
209	216	212	202	198	195	192	189	185	179	171	162	151	137

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

Density (20 °C) kg/dm³	100°C 10E-6/K	200°C 10E-6/K	300°C 10E-6/K	400°C 10E-6/K	500°C 10E-6/K	600°C 10E-6/K	700°C 10E-6/K	800°C 10E-6/K	Heat cond. W/Km	Heat capac. J/kgK
7,85	12,1	12,7	13,3	13,8	14,4	...	...	...	...	...