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Appendix

A	Material documentation	A1-A15

Layout

Input values:	*1.234*	or	1.234
Calculated values:	***1.234***	or	**1.234**
Critical values:	*1.234*	or	1.234
Estimated values:	*1.234*	or	1.234

1 E4.18.6 D1
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

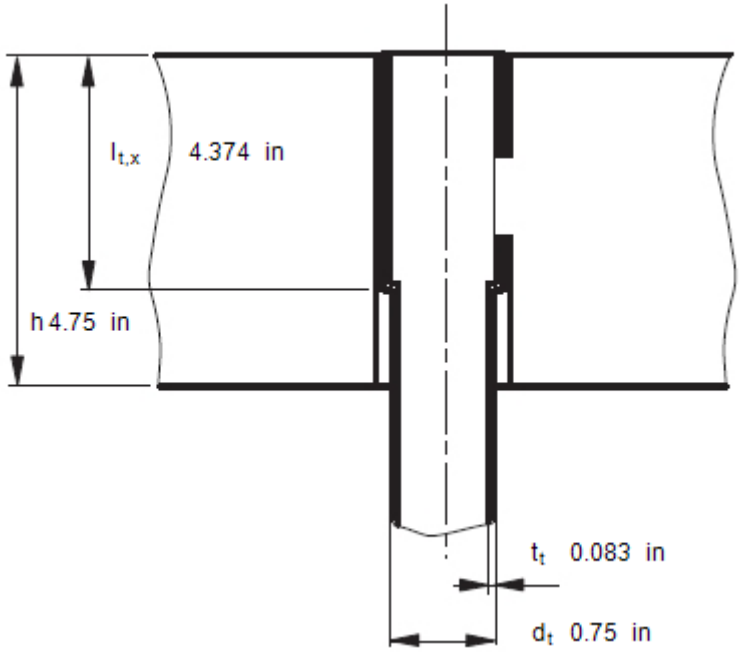
Configuration of the tubesheet (a, b, c, d)	Type	*b*		(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)		*1*		(1,2)
Internal operation pressure shell side	P_s	*335*	psi	
Internal operation pressure tube side	P_t	*1040*	psi	
Internal 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 per UHX-13.4(a): (1-D1), (2-D2), (3-D3)		1		(1-3)
Calculation case per UHX-13.4(a): (4-O4),(5-O1), (6-O2), (7-O3)		1		(4-7)
Tube side pressure only (Ps=0) without differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*675*	°F	*650*	°F	*675*	°F
Thickness		*4.75*	in	*0.083*	in	*0.5*	in
Outside diameter		*32.88*	in	*0.75*	in	*24*	in
Poisson's ratio	-			*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0.25*	in	*0*	in	*0.125*	in
Properties for the selected load case temperature							
Strength operat.		18355	psi	10927	psi	18355	psi
Safety operation		1		1		1	
Young's modulus		*2.558e+7*	psi	*2.608e+7*	psi	*2.579e+7*	psi
Thermal expansion		*7.548*	1E-6/°F	*7.509*	1E-6/°F	*7.548*	1E-6/°F
Yield strength		*27741*	psi	*19300*	psi	*27741*	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		*18450*	psi	***10927***	psi	***18355***	psi
Prim.+sec. str.		***55481***	psi			***55481***	psi
Properties for testing at 20°C							
Strength	*)	33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

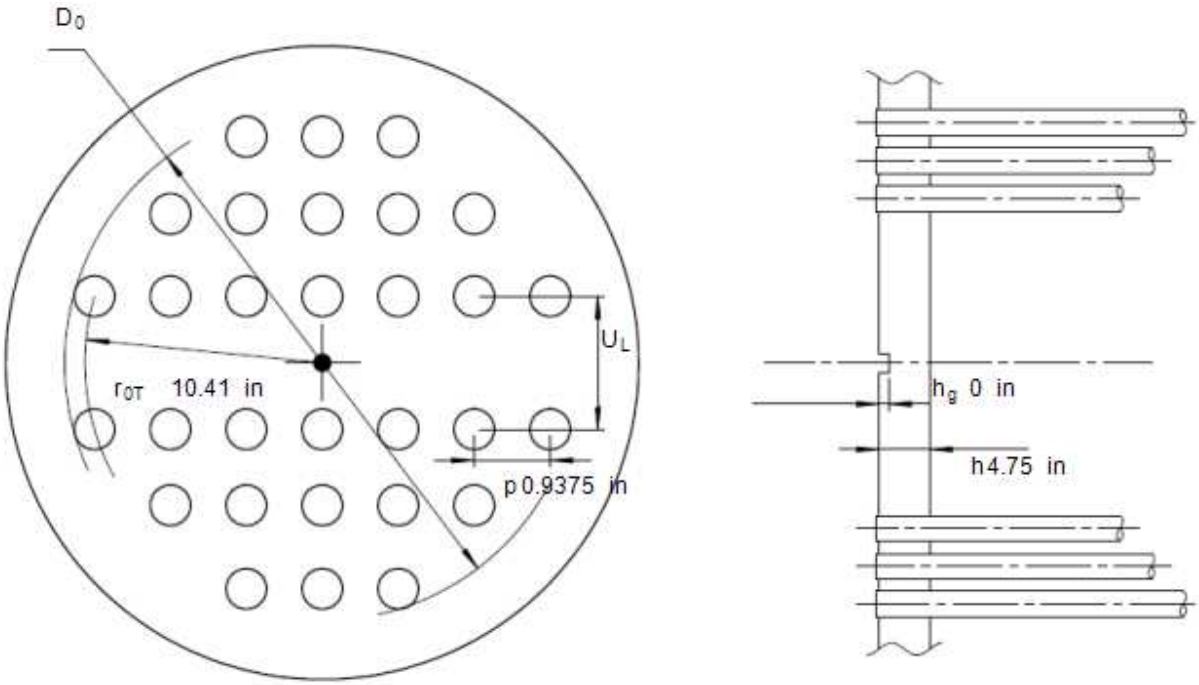
Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*434*	



Expanded length of tube in tubesheet		$l_{t,x}$	*4.374*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*10.41*	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	*0.9375*	in



Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*135.1*	in
Unsupported tube span for buckling	l	34	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	1	
Equivalent free buckling length k·l	l_t	***34***	in
Bellows inside diameter at its convolution height	D_j	*29.46*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*14759*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	-
Material properties for mean operation temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*490*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.28*	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material	*K02700-SA-516-70-Class:-Size:*			
Increased shell thickness with allowances		t_{1s}	*1.25*	in
Thickness allowance		c_{1s}	0	in
Corrosion allowance		c_{2s}	*0.125*	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)		l_1	*9.875*	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)		l'_1	*9.875*	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$		l_{min}	***9.206***	in
Yield strength of shell at T_s =	***675*** °F	S_{y1s}	*27741*	psi
Strength of shell at T_s		K_{1s}	18355	psi
Safety factor of shell at T_s		S_{s1}	1	
Allowable stress for shell at T_s		S_{1s}	***18355***	psi
Tensile strength at room temperature 20°C		S_{z1s}	70343	psi
Limit temperature for time dependent properties		T_{G1s}	752	°F
Allowable primary and secondary stress at T_s		S_{ps1s}	***55482***	psi
E-Modulus of shell at T_s		E_{1s}	*2.579e+7*	psi
Mean coefficient of thermal expansion at T_{sm}		α_{sm1}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*30.12*	in
Number of bolts	n	*28*	-
Bolt root diameter	d_B	*1.213*	in
Total bolt area	A_b	***32.36***	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	*1*	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	*26.13*	in
Contact inside diameter	G_i		in	25.12	in
Basic seating width	b_0		in	*0.25*	in
Gasket factor (Table 2-5.1)	m			*6.5*	
Gasket seating pressure	Y		psi	*26000*	psi
Diameter of gasket force	G		in	***25.63***	in
Poisson's ratio	v	*0.3*		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**806110**	lbf
Total req. bolt root area	A_m	**0**	in²	**32.31**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.709**	in

Maximum bolt force for all calculation cases	W_{max}	*808478*	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**806655**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.002501**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.375**	in
Shell inside diameter corroded (type abc)	D_s	**23.25**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.6397**	in
Effective pitch	p*	**0.9375**	in
Effective ligament efficiency for shear	μ*	**0.3176**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**10.78**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**12.81**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**11.62**	in
Ratio = ac/a0	ρ_C	**1.189**	
Ratio = as/a0	ρ_S	**1.078**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4749**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6816**	
Type abc: Coefficients for shell pressure	δ_S	**0.01458**	mm^3/N
β_S **4.166** 1/ft k_S **2335050** lbf	λ_S	**1.352e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	**5886426**	lbf/in
Tube axial rigidity	K_t	**33564**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.4041**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.002501**	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	**7782575**	psi
Ratio of elasticity tubesheet	E*/E	**0.3043**	
effective Poisson's ratio tubesheet	v*	**0.3427**	
Parameter for table UHX-13.1	X_a	**2.003**	
Z_d **0.1725** Z_v **0.1602** Z_m **0.6667** Z_a **0.8146**	Z_w	**0.1602**	

Step 4

Diameter ratio = A/D0	K	**1.525**	
F **2.053** Φ **2.757**	Q_1	**-0.128**	
Q_{z1} **1.223** Q_{z2} **0.6023**	U	**1.205**	

UHX-13.5.5 Step 5, coefficients

γ(*) **0** in ω_S **8.865** in²	ω_S*	**-8.495**	in²
ω_C **0** in² ω_C* **8.674** in²	γ_b	**-0.2085**	

Results acc. UHX-13.8 Radial differential thermal expansion

T_r **68** °F T_s* **68** °F	T_c*	**68**	°F
P_s* **0** psi P_c* **0** psi	P_ω	**0**	psi

Step 6

P_s' **0** psi P_t' **1029949** psi	P_γ	**0**	psi
P_W **278.1** psi P_{rim} **93.49** psi	P_e	**-1039**	psi

UHX-13.5.7 Step 7

Q_2 **-12634** lbf Q_3 **0.08119**	F_m	**0.1979**	

Strength condition for the tubesheet bending stress, case 1

σ = **22297** psi	< 1.5 · σ_B	= 1.5·	*18450*	psi	case 1-3	
	< S_{PS}	=	***55481***	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14760** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 *Y* **)**

F_{tmin}	**0.453**		F_{tmax}	**1.493**	
x_{min}	**0**		x_{max}	**2.003**	
$\sigma_{T,1}$	**-1152**	psi	$\sigma_{T,2}$	**4076**	psi

σ_{tmax} = **4076** psi ≤ σ_T = **10927** psi for calculation case 1-3

≤2 · σ_T = **21854** psi for calculation case 4-7

Tube weld force W_t = **708.9** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t **0.2376** in F_t **143.1** C_t **2** F_s **163.3**

$|\sigma_{tmin}|$ = | **-1152** psi | ≤S_{tb} = **5423** psi (only σ_{tmin} < 0 buckl.)

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.5* in : (calculation case)

σ_{Sm} ≤ *1*· ***18355*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **10.4** psi ≤2· ***18355*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

10.4 psi	< Min(**10757** psi , **50379** psi)

ASME external pressure chart CS-2 A = **0.003906**

Region of increased thickness t_{1s} = *1.25* in : (calculation case)

σ_{Sm} ≤ *1*· ***18355*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **3.359** psi ≤2· ***18355*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

3.359 psi	< Min(**12539** psi , **142247** psi)

ASME external pressure chart CS-2 A = **0.01103**

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **41086** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **3.359** psi | + | **-41083** psi | ≤ **27533** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is violated!

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3
Shell	**2.579e+7** psi	**2.579e+7** psi
Channel	psi	psi

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:

σ_S = **41086** psi ≤ ***55481*** psi $=S_{PSs}$

with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:

σ_C = **0** psi ≤ ***0*** psi $=S_{PSc}$

Geometric conditions:

valid

Strength condition for linked modules (Connection activated: Yes):

Strength violated for calculation case: 1 3

13.4(d) If: Tube sheet thickness= *4.75* in < *0.75* in

= Tube outside diameter, the tubesheet deformation must be considered.

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· ***18355*** psi or 2· *27741* psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1030898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5878\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{176335\ \text{MPa}} \cdot \frac{75.34\ \text{MPa}}{127.2\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.25\ \text{mm}}{16.25\ \text{mm}} = 0.3176$$

2 E4.18.6 D2
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Fixed tubesheets according to ASME-UHX-13

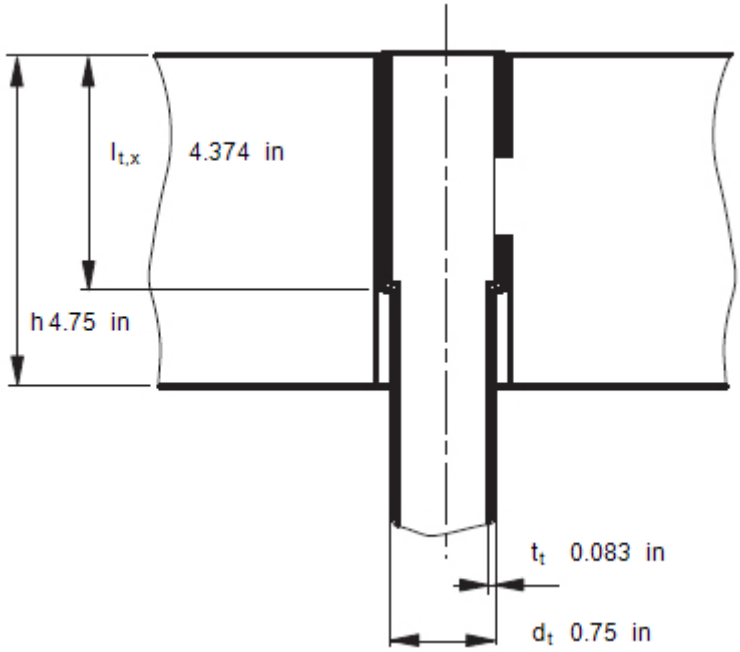
Configuration of the tubesheet (a, b, c, d)	Type	*b*		(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)		*1*		(1,2)
Internal operation pressure shell side	P_s	*335*	psi	
Internal operation pressure tube side	P_t	*1040*	psi	
Internal 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 per UHX-13.4(a): (1-D1), (2-D2), (3-D3)		2		(1-3)
Calculation case per UHX-13.4(a): (4-O4),(5-O1), (6-O2), (7-O3)		2		(4-7)
Shell side pressure only (Pt=0) without differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*675*	°F	*650*	°F	*675*	°F
Thickness		*4.75*	in	*0.083*	in	*0.5*	in
Outside diameter		*32.88*	in	*0.75*	in	*24*	in
Poisson's ratio		-		*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0.25*	in	*0*	in	*0.125*	in
Properties for the selected load case temperature							
Strength operat.		18355	psi	10927	psi	18355	psi
Safety operation		1		1		1	
Young's modulus		*2.558e+7*	psi	*2.608e+7*	psi	*2.579e+7*	psi
Thermal expansion		*7.548*	1E-6/°F	*7.509*	1E-6/°F	*7.548*	1E-6/°F
Yield strength		*27741*	psi	*19300*	psi	*27741*	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		*18450*	psi	*12588*	psi	***18355***	psi
Prim.+sec. str.		*55481*	psi			***55481***	psi
Properties for testing at 20°C							
Strength	*)	33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

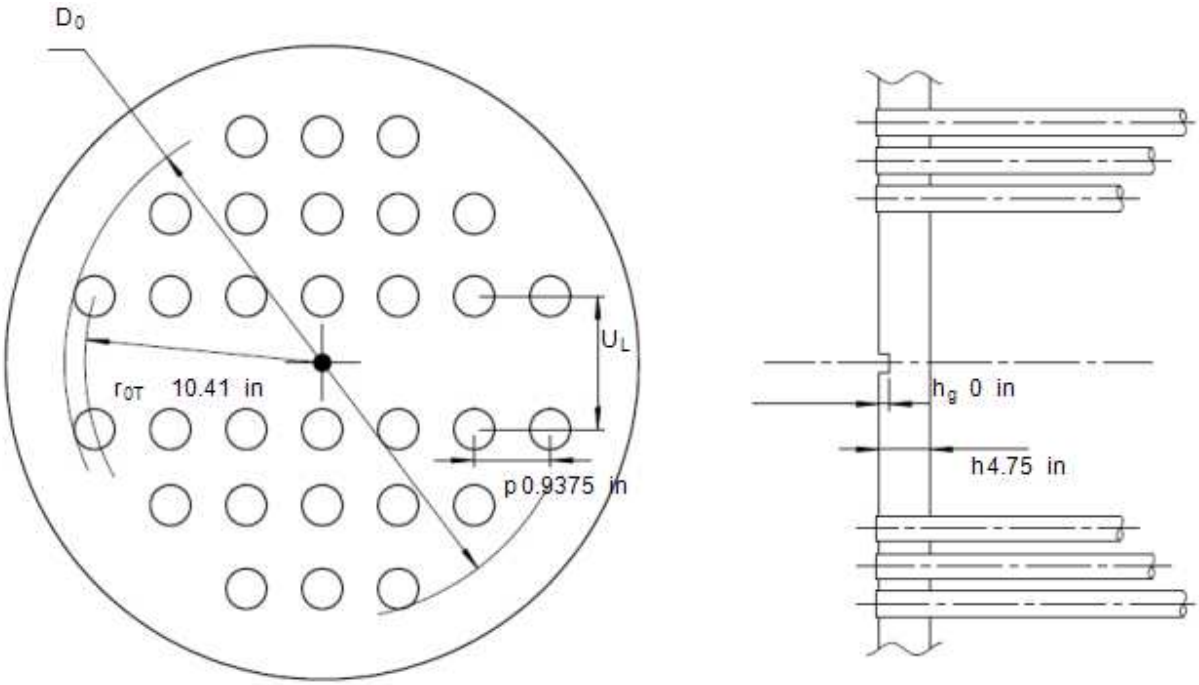
Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*434*	



Expanded length of tube in tubesheet		$l_{t,x}$	*4.374*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*10.41*	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	*0.9375*	in



Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*135.1*	in
Unsupported tube span for buckling	l		in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k		
Equivalent free buckling length k·l	l_t	*34*	in
Bellows inside diameter at its convolution height	D_j	*29.46*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*14759*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	-

Material properties for mean operation temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*490*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.28*	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material	*K02700-SA-516-70-Class:-Size:*			
Increased shell thickness with allowances		t_{1s}	*1.25*	in
Thickness allowance		c_{1s}	0	in
Corrosion allowance		c_{2s}	*0.125*	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)		l_1	*9.875*	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)		l'_1	*9.875*	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$		l_{min}	**9.206**	in
Yield strength of shell at T_s =	**675** °F	S_{y1s}	*27741*	psi
Strength of shell at T_s		K_{1s}	18355	psi
Safety factor of shell at T_s		S_{s1}	1	
Allowable stress for shell at T_s		S_{1s}	*18355*	psi
Tensile strength at room temperature 20°C		S_{z1s}	70343	psi
Limit temperature for time dependent properties		T_{G1s}	752	°F
Allowable primary and secondary stress at T_s		S_{ps1s}	*55482*	psi
E-Modulus of shell at T_s		E_{1s}	*2.579e+7*	psi
Mean coefficient of thermal expansion at T_{sm}		α_{sm1}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*30.12*	in
Number of bolts	n	*28*	-
Bolt root diameter	d_B	*1.213*	in
Total bolt area	A_b	**32.36**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	*1*	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	*26.13*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.25*	in
Gasket factor (Table 2-5.1)	m			*6.5*	
Gasket seating pressure	Y		psi	*26000*	psi
Diameter of gasket force	G		in	***25.63***	in
Poisson's ratio	v	*0.3*		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.8**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.35**	in

Maximum bolt force for all calculation cases	W_{max}	0	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**663079**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.002501**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.375**	in
Shell inside diameter corroded (type abc)	D_s	**23.25**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.6397**	in
Effective pitch	p*	**0.9375**	in
Effective ligament efficiency for shear	μ*	**0.3176**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**10.78**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**12.81**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**11.62**	in
Ratio = ac/a0	ρ_C	**1.189**	
Ratio = as/a0	ρ_S	**1.078**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4749**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6816**	
Type abc: Coefficients for shell pressure	δ_S	**0.01458**	mm^3/N
β_S **4.166** 1/ft k_S **2335050** lbf	λ_S	**1.352e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	**5886426**	lbf/in
Tube axial rigidity	K_t	**33564**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.4041**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.002501**	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	**7782575**	psi
Ratio of elasticity tubesheet	E*/E	**0.3043**	
effective Poisson's ratio tubesheet	v*	**0.3427**	
Parameter for table UHX-13.1	X_a	**2.003**	
Z_d **0.1725** Z_v **0.1602** Z_m **0.6667** Z_a **0.8146**	Z_w	**0.1602**	

Step 4

Diameter ratio = A/D0	K	**1.525**	
F **2.053** Φ **2.757**	Q_1	**-0.128**	
Q_{z1} **1.223** Q_{z2} **0.6023**	U	**1.205**	

UHX-13.5.5 Step 5, coefficients

γ(*) **0** in ω_S **8.865** in²	ω_S*	**-8.495**	in²
ω_C **0** in² ω_C* **8.674** in²	γ_b	**-0.2085**	

Results acc. UHX-13.8 Radial differential thermal expansion

T_r **68** °F T_s* **68** °F	T_c*	**68**	°F
P_s* **0** psi P_c* **0** psi	P_ω	**0**	psi

Step 6

P_s' **-169482** psi P_t' **0** psi	P_γ	**0**	psi
P_W **228.1** psi P_{rim} **29.49** psi	P_e	**-170.8**	psi

UHX-13.5.7 Step 7

Q_2 **-1003** lbf Q_3 **-0.02697**	F_m	**0.157**	

Strength condition for the tubesheet bending stress, case 2

σ = **2907** psi	< 1.5 · σ_B	= 1.5·	*18450*	psi	case 1-3	
	< S_{PS}	=	*55481*	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14760** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 *Y* **)**

F_{tmin}	**0.585**		F_{tmax}	**1.354**	
x_{min}	**0**		x_{max}	**2.003**	
$\sigma_{T,1}$	**1253**	psi	$\sigma_{T,2}$	**1888**	psi

σ_{tmax} = **1888** psi ≤ σ_T = *12588* psi for calculation case 1-3

≤2 · σ_T = **25176** psi for calculation case 4-7

Tube weld force W_t = **328.4** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	**0.2376**	in	F_t	**143.1**	C_t	**2**	F_s	**163.3**

$|\sigma_{tmin}|$ = | **1253** psi | ≤S_{tb} = **5423** psi (only σ_{tmin} < 0 buckl.)

Strength acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.5* in : (calculation case)

σ_{Sm} ≤ *1*· ***18355*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-1526** psi ≤2· ***18355*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-1526**	psi	| < Min(	**10757**	psi	, **50379**	psi	)

ASME external pressure chart CS-2 A = **0.003906**

Region of increased thickness t_{1s} = *1.25* in : (calculation case)

σ_{Sm} ≤ *1*· *18355* psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-493** psi ≤2· *18355* psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-493**	psi	| < Min(	**12539**	psi	, **142247**	psi	)

ASME external pressure chart CS-2 A = **0.01103**

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **1109** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-493** psi | + | **615.7** psi | ≤ **27533** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3	
Shell	**2.579e+7** psi	**2.579e+7** psi	
Channel	psi	psi	

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:
σ_S = **1109** psi ≤ ***55481*** psi $=S_{PSs}$
with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:
σ_C = **0** psi ≤ *0* psi $=S_{PSc}$

Geometric conditions:
valid

Strength condition for linked modules (Connection activated: No):
13.4(d) If: Tube sheet thickness= *4.75* in < *0.75* in
= Tube outside diameter, the tubesheet deformation must be considered.
UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· ***18355*** psi or 2· *27741* psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1030898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5878\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{176335\ \text{MPa}} \cdot \frac{86.79\ \text{MPa}}{127.2\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.25\ \text{mm}}{16.25\ \text{mm}} = 0.3176$$

3 E4.18.6 D3
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	*b*		(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)		*1*		(1,2)
Internal operation pressure shell side	P_s	*335*	psi	
Internal operation pressure tube side	P_t	*1040*	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 per UHX-13.4(a): (1-D1), (2-D2), (3-D3)		3		(1-3)
Calculation case per UHX-13.4(a): (4-O4),(5-O1), (6-O2), (7-O3)		3		(4-7)
Tube and shell side pressure acting without differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*675*	°F	*650*	°F	*675*	°F
Thickness		*4.75*	in	*0.083*	in	*0.5*	in
Outside diameter		*32.88*	in	*0.75*	in	*24*	in
Poisson's ratio	-			*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0.25*	in	*0*	in	*0.125*	in

Properties for the selected load case temperature

Strength operat.	18355	psi	10927	psi	18355	psi
Safety operation	1		1		1	
Young's modulus	*2.558e+7*	psi	*2.608e+7*	psi	*2.579e+7*	psi
Thermal expansion	*7.548*	1E-6/°F	*7.509*	1E-6/°F	*7.548*	1E-6/°F
Yield strength	*27741*	psi	*19300*	psi	*27741*	psi
Limit temperature	752	°F	752	°F	752	°F
Allow. stress	*18450*	psi	*12588*	psi	***18355***	psi
Prim.+sec. str.	*55481*	psi			***55481***	psi

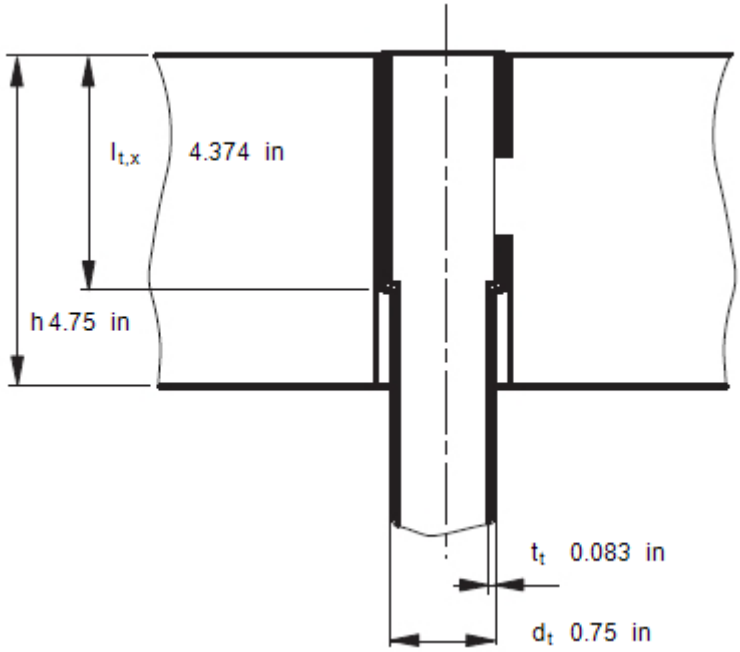
Properties for testing at 20°C

Strength *)	33939	psi	23496	psi	33939	psi
Safety factor	1		1		1	
Yield strength	37710	psi	26107	psi	37710	psi
Tensile strength	70343	psi	47137	psi	70343	psi

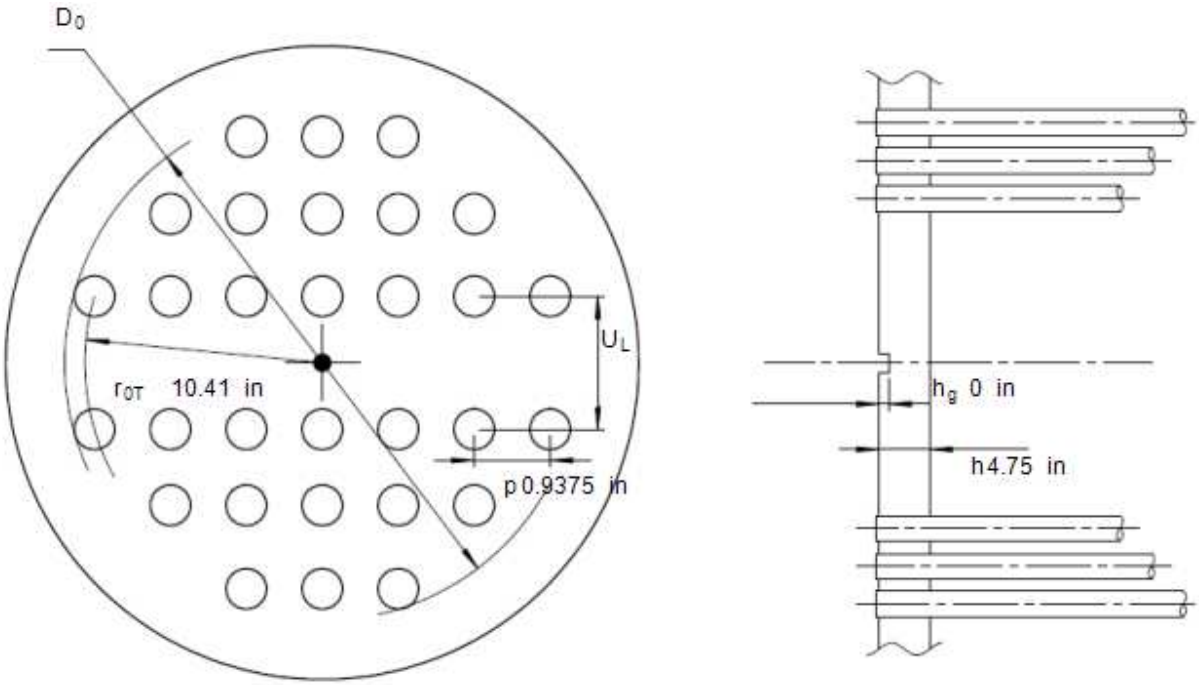
Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*434*	



Expanded length of tube in tubesheet		$l_{t,x}$	*4.374*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*10.41*	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	*0.9375*	in



Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*135.1*	in
Unsupported tube span for buckling	l		in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k		
Equivalent free buckling length k·l	l_t	*34*	in
Bellows inside diameter at its convolution height	D_j	*29.46*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*14759*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	-

Material properties for mean operation temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*490*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.28*	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material	*K02700-SA-516-70-Class:-Size:*			
Increased shell thickness with allowances		t_{1s}	*1.25*	in
Thickness allowance		c_{1s}	0	in
Corrosion allowance		c_{2s}	*0.125*	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)		l_1	*9.875*	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)		l'_1	*9.875*	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$		l_{min}	**9.206**	in
Yield strength of shell at T_s =	**675** °F	S_{y1s}	*27741*	psi
Strength of shell at T_s		K_{1s}	18355	psi
Safety factor of shell at T_s		S_{s1}	1	
Allowable stress for shell at T_s		S_{1s}	*18355*	psi
Tensile strength at room temperature 20°C		S_{z1s}	70343	psi
Limit temperature for time dependent properties		T_{G1s}	752	°F
Allowable primary and secondary stress at T_s		S_{ps1s}	*55482*	psi
E-Modulus of shell at T_s		E_{1s}	*2.579e+7*	psi
Mean coefficient of thermal expansion at T_{sm}		α_{sm1}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*30.12*	in
Number of bolts	n	*28*	-
Bolt root diameter	d_B	*1.213*	in
Total bolt area	A_b	**32.36**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	*1*	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	*26.13*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.25*	in
Gasket factor (Table 2-5.1)	m			*6.5*	
Gasket seating pressure	Y		psi	*26000*	psi
Diameter of gasket force	G		in	***25.63***	in
Poisson's ratio	v	*0.3*		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**806110**	lbf
Total req. bolt root area	A_m	**0**	in²	**32.31**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.709**	in

Maximum bolt force for all calculation cases	W_{max}	*808478*	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**806655**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.002501**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.375**	in
Shell inside diameter corroded (type abc)	D_s	**23.25**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.6397**	in
Effective pitch	p*	**0.9375**	in
Effective ligament efficiency for shear	μ*	**0.3176**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**10.78**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**12.81**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**11.62**	in
Ratio = ac/a0	ρ_C	**1.189**	
Ratio = as/a0	ρ_S	**1.078**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4749**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6816**	
Type abc: Coefficients for shell pressure	δ_S	**0.01458**	mm^3/N
β_S **4.166** 1/ft k_S **2335050** lbf	λ_S	**1.352e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	**5886426**	lbf/in
Tube axial rigidity	K_t	**33564**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.4041**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.002501**	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	**7782575**	psi
Ratio of elasticity tubesheet	E*/E	**0.3043**	
effective Poisson's ratio tubesheet	v*	**0.3427**	
Parameter for table UHX-13.1	X_a	**2.003**	
Z_d **0.1725** Z_v **0.1602** Z_m **0.6667** Z_a **0.8146**	Z_w	**0.1602**	

Step 4

Diameter ratio = A/D0	K	**1.525**	
F **2.053** Φ **2.757**	Q_1	**-0.128**	
Q_{z1} **1.223** Q_{z2} **0.6023**	U	**1.205**	

UHX-13.5.5 Step 5, coefficients

γ(*) **0** in ω_S **8.865** in²	ω_S*	**-8.495**	in²
ω_C **0** in² ω_C* **8.674** in²	γ_b	**-0.2085**	

Results acc. UHX-13.8 Radial differential thermal expansion

T_r **68** °F T_s* **68** °F	T_c*	**68**	°F
P_s* **0** psi P_c* **0** psi	P_ω	**0**	psi

Step 6

P_s' **-169482** psi P_t' **1029949** psi	P_γ	**0**	psi
P_W **278.1** psi P_{rim} **123** psi	P_e	**-1210**	psi

UHX-13.5.7 Step 7

Q_2 **-13636** lbf Q_3 **0.06589**	F_m	**0.1921**	

Strength condition for the tubesheet bending stress, case 3

σ = **25207** psi	< 1.5 · σ_B	= 1.5·	*18450*	psi	case 1-3	
	< S_{PS}	=	*55481*	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14760** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 *Y* **)**

F_{tmin}	**0.4717**		F_{tmax}	**1.473**	
x_{min}	**0**		x_{max}	**2.003**	
$\sigma_{T,1}$	**101.9** psi		$\sigma_{T,2}$	**5965** psi	

σ_{tmax} = **5965** psi ≤ σ_T = *12588* psi for calculation case 1-3

≤2 · σ_T = **25176** psi for calculation case 4-7

Tube weld force W_t = **1038** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	**0.2376** in	F_t	**143.1**	C_t	**2**	F_s	**163.3**

$|\sigma_{tmin}|$ = | **101.9** psi | ≤S_{tb} = **5423** psi (only σ_{tmin} < 0 buckl.)

Strength acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.5* in : (calculation case)

σ_{Sm} ≤ *1*· ***18355*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-1518** psi ≤2· ***18355*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

| **-1518** psi |	< Min(	**10757** psi	,	**50379** psi	)		
ASME external pressure chart	CS-2		A	=	**0.003906**		

Region of increased thickness t_{1s} = *1.25* in : (calculation case)

σ_{Sm} ≤ *1*· *18355* psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-490.6** psi ≤2· *18355* psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

| **-490.6** psi |	< Min(	**12539** psi	,	**142247** psi	)		
ASME external pressure chart	CS-2		A	=	**0.01103**		

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **40961** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-490.6** psi | + | **-40471** psi | ≤ **27533** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is violated!

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3
Shell	**2.579e+7** psi	**2.579e+7** psi
Channel	psi	psi

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:

σ_S = **40961** psi ≤ ***55481*** psi $=S_{PSs}$

with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:

σ_C = **0** psi ≤ *0* psi $=S_{PSc}$

Geometric conditions:

valid

Strength condition for linked modules (Connection activated: No):

13.4(d) If: Tube sheet thickness= *4.75* in < *0.75* in

= Tube outside diameter, the tubesheet deformation must be considered.

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· ***18355*** psi or 2· *27741* psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1030898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5878\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{176335\ \text{MPa}} \cdot \frac{86.79\ \text{MPa}}{127.2\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.25\ \text{mm}}{16.25\ \text{mm}} = 0.3176$$

4 E4.18.6 O4
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

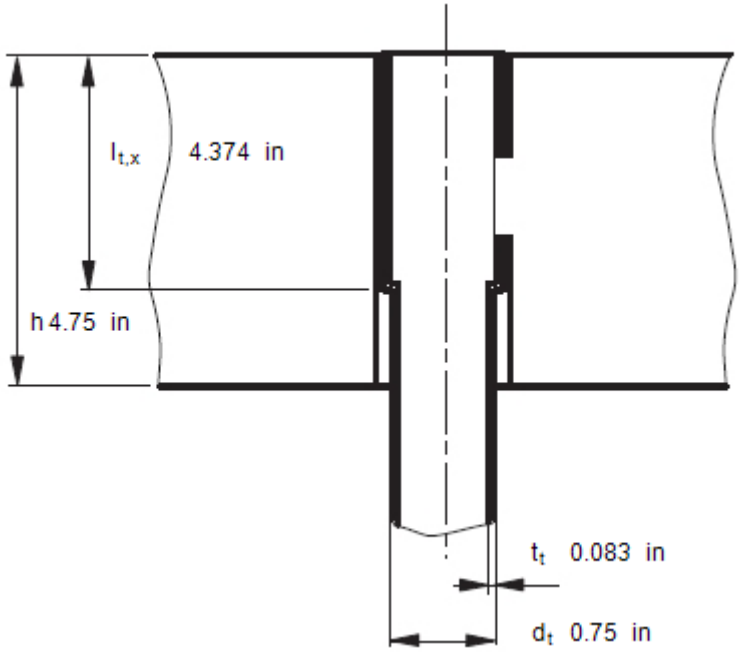
Configuration of the tubesheet (a, b, c, d)	Type	*b*		(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)		*1*		(1,2)
Internal operation pressure shell side	P_s	*335*	psi	
Internal operation pressure tube side	P_t	*1040*	psi	
Internal 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 per UHX-13.4(a): (1-D1), (2-D2), (3-D3)		4		(1-3)
Calculation case per UHX-13.4(a): (4-O4),(5-O1), (6-O2), (7-O3)		4		(4-7)
Differential thermal expansion only (Ps=Pt=0)				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*675*	°F	*650*	°F	*675*	°F
Thickness		*4.75*	in	*0.083*	in	*0.5*	in
Outside diameter		*32.88*	in	*0.75*	in	*24*	in
Poisson's ratio	-			*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0.25*	in	*0*	in	*0.125*	in
Properties for the selected load case temperature							
Strength operat.		18355	psi	10927	psi	18355	psi
Safety operation		1		1		1	
Young's modulus		*2.558e+7*	psi	*2.608e+7*	psi	*2.579e+7*	psi
Thermal expansion		*7.548*	1E-6/°F	*7.509*	1E-6/°F	*7.548*	1E-6/°F
Yield strength		*27741*	psi	*19300*	psi	*27741*	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		*18450*	psi	*12588*	psi	***18355***	psi
Prim.+sec. str.		*55481*	psi			***55481***	psi
Properties for testing at 20°C							
Strength	*)	33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

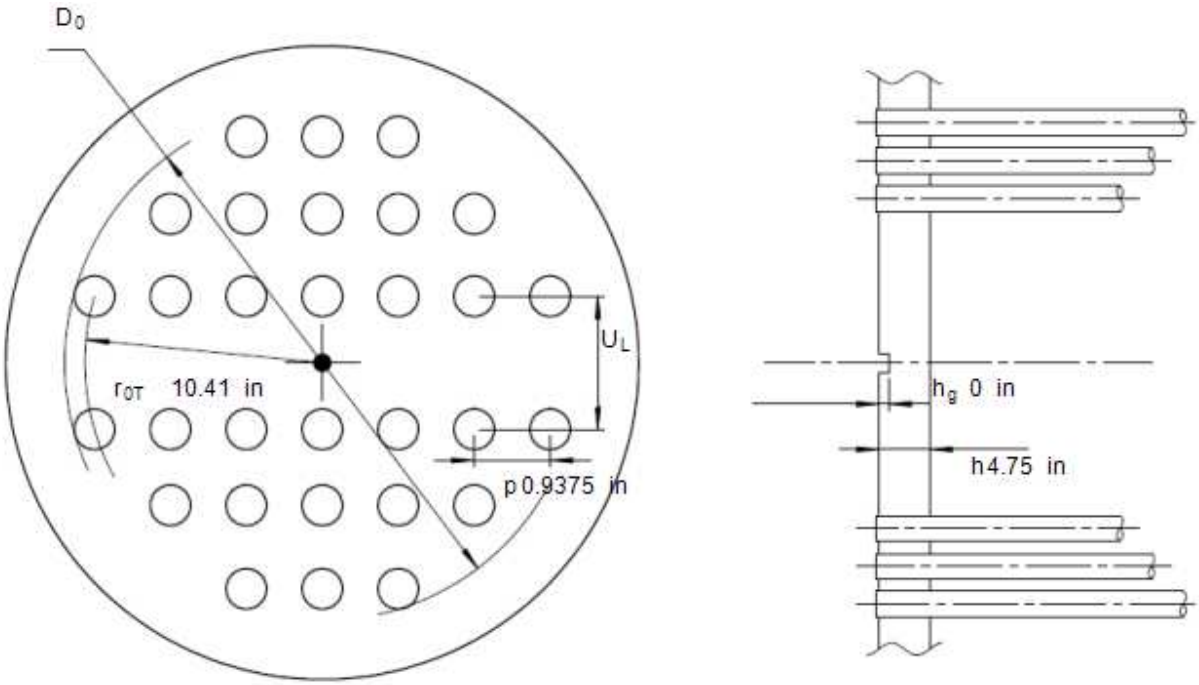
Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*434*	



Expanded length of tube in tubesheet		$l_{t,x}$	*4.374*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*10.41*	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	*0.9375*	in



Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*135.1*	in
Unsupported tube span for buckling	l		in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k		
Equivalent free buckling length k·l	l_t	*34*	in
Bellows inside diameter at its convolution height	D_j	*29.46*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*14759*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	-
Material properties for mean operation temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*490*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.28*	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material	*K02700-SA-516-70-Class:-Size:*		
Increased shell thickness with allowances	t_{1s}	*1.25*	in
Thickness allowance	c_{1s}	0	in
Corrosion allowance	c_{2s}	*0.125*	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)	l_1	*9.875*	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)	l'_1	*9.875*	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$	l_{min}	**9.206**	in
Yield strength of shell at T_s = **675** °F	S_{y1s}	*27741*	psi
Strength of shell at T_s	K_{1s}	18355	psi
Safety factor of shell at T_s	S_{s1}	1	
Allowable stress for shell at T_s	S_{1s}	*18355*	psi
Tensile strength at room temperature 20°C	S_{z1s}	70343	psi
Limit temperature for time dependent properties	T_{G1s}	752	°F
Allowable primary and secondary stress at T_s	S_{ps1s}	*55482*	psi
E-Modulus of shell at T_s	E_{1s}	*2.579e+7*	psi
Mean coefficient of thermal expansion at T_{sm}	α_{sm1}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*30.12*	in
Number of bolts	n	*28*	-
Bolt root diameter	d_B	*1.213*	in
Total bolt area	A_b	**32.36**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	*1*	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	*26.13*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.25*	in
Gasket factor (Table 2-5.1)	m			*6.5*	
Gasket seating pressure	Y		psi	*26000*	psi
Diameter of gasket force	G		in	***25.63***	in
Poisson's ratio	v	*0.3*		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.8**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.709**	in

Maximum bolt force for all calculation cases	W_{max}	*808478*	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**663079**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.002501**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.375**	in
Shell inside diameter corroded (type abc)	D_s	**23.25**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.6397**	in
Effective pitch	p*	**0.9375**	in
Effective ligament efficiency for shear	μ*	**0.3176**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**10.78**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**12.81**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**11.62**	in
Ratio = ac/a0	ρ_C	**1.189**	
Ratio = as/a0	ρ_S	**1.078**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4749**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6816**	
Type abc: Coefficients for shell pressure	δ_S	**0.01458**	mm^3/N
β_S **4.166** 1/ft k_S **2335050** lbf	λ_S	**1.352e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	**5886426**	lbf/in
Tube axial rigidity	K_t	**33564**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.4041**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.002501**	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	**7782575**	psi
Ratio of elasticity tubesheet	E*/E	**0.3043**	
effective Poisson's ratio tubesheet	v*	**0.3427**	
Parameter for table UHX-13.1	X_a	**2.003**	
Z_d **0.1725** Z_v **0.1602** Z_m **0.6667** Z_a **0.8146**	Z_w	**0.1602**	

Step 4

Diameter ratio = A/D0	K	**1.525**	
F **2.053** Φ **2.757**	Q_1	**-0.128**	
Q_{z1} **1.223** Q_{z2} **0.6023**	U	**1.205**	

UHX-13.5.5 Step 5, coefficients

γ(*) **-0.06033** in ω_S **8.865** in²	ω_S*	**-8.495**	in²
ω_C **0** in² ω_C* **8.674** in²	γ_b	**-0.2085**	

Results acc. UHX-13.8 Radial differential thermal expansion

T_r **68** °F T_s* **68** °F	T_c*	**68**	°F
P_s* **0** psi P_c* **0** psi	P_ω	**0**	psi

Step 6

P_s' **0** psi P_t' **0** psi	P_γ	**-2407**	psi
P_W **278.1** psi P_{rim} **0** psi	P_e	**-2.148**	psi

UHX-13.5.7 Step 7

Q_2 **-9455** lbf Q_3 **75.59**	F_m	**37.85**	

Strength condition for the tubesheet bending stress, case 4

σ = **8818** psi	< 1.5 · σ_B	= 1.5·	*18450*	psi	case 1-3	
	< S_{PS}	=	*55481*	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14760** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 *Y* **)**

F_{tmin}	**-91.65**		F_{tmax}	**98.84**	
x_{min}	**0**		x_{max}	**2.003**	
$\sigma_{T,1}$	**-952.5**	psi	$\sigma_{T,2}$	**1027**	psi

σ_{tmax} = **1027** psi ≤ σ_T = *12588* psi for calculation case 1-3

≤2 · σ_T = **25176** psi for calculation case 4-7

Tube weld force W_t = **178.7** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	**0.2376**	in	F_t	**143.1**	C_t	**1.25**	F_s	**163.3**

$|\sigma_{tmin}|$ = | **-952.5** psi | ≤S_{tb} = **8677** psi (only σ_{tmin} < 0 buckl.)

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.5* in : (calculation case)

σ_{Sm} ≤ *1*· ***18355*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-28.19** psi ≤2· ***18355*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-28.19** psi	|	< Min(	**10757** psi	,	**50379** psi	)
ASME external pressure chart		CS-2		A	=	**0.003906**		

Region of increased thickness t_{1s} = *1.25* in : (calculation case)

σ_{Sm} ≤ *1*· *18355* psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-9.107** psi ≤2· *18355* psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-9.107** psi	|	< Min(	**12539** psi	,	**142247** psi	)
ASME external pressure chart		CS-2		A	=	**0.01103**		

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **20048** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-9.107** psi | + | **-20039** psi | ≤ **55482** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3	
Shell	**2.579e+7** psi	**2.579e+7** psi	
Channel	psi	psi	

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:
σ_S = **20048** psi ≤ ***55481*** psi $=S_{PSs}$
with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:
σ_C = **0** psi ≤ *0* psi $=S_{PSc}$

Geometric conditions:
valid

Strength condition for linked modules (Connection activated: No):
13.4(d) If: Tube sheet thickness= *4.75* in < *0.75* in
= Tube outside diameter, the tubesheet deformation must be considered.
UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· ***18355*** psi or 2· *27741* psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1030898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5878\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{176335\ \text{MPa}} \cdot \frac{86.79\ \text{MPa}}{127.2\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.25\ \text{mm}}{16.25\ \text{mm}} = 0.3176$$

5 E4.18.6 O1
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	*b*		(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)		*1*		(1,2)
Internal operation pressure shell side	P_s	*335*	psi	
Internal operation pressure tube side	P_t	*1040*	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 per UHX-13.4(a): (1-D1), (2-D2), (3-D3)		5		(1-3)
Calculation case per UHX-13.4(a): (4-O4),(5-O1), (6-O2), (7-O3)		5		(4-7)
Tube side pressure only (Ps=0) with differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*675*	°F	*650*	°F	*675*	°F
Thickness		*4.75*	in	*0.083*	in	*0.5*	in
Outside diameter		*32.88*	in	*0.75*	in	*24*	in
Poisson's ratio		-		*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0.25*	in	*0*	in	*0.125*	in

Properties for the selected load case temperature

Strength operat.	18355	psi	10927	psi	18355	psi
Safety operation	1		1		1	
Young's modulus	*2.558e+7*	psi	*2.608e+7*	psi	*2.579e+7*	psi
Thermal expansion	*7.548*	1E-6/°F	*7.509*	1E-6/°F	*7.548*	1E-6/°F
Yield strength	*27741*	psi	*19300*	psi	*27741*	psi
Limit temperature	752	°F	752	°F	752	°F
Allow. stress	*18450*	psi	*12588*	psi	***18355***	psi
Prim.+sec. str.	*55481*	psi			***55481***	psi

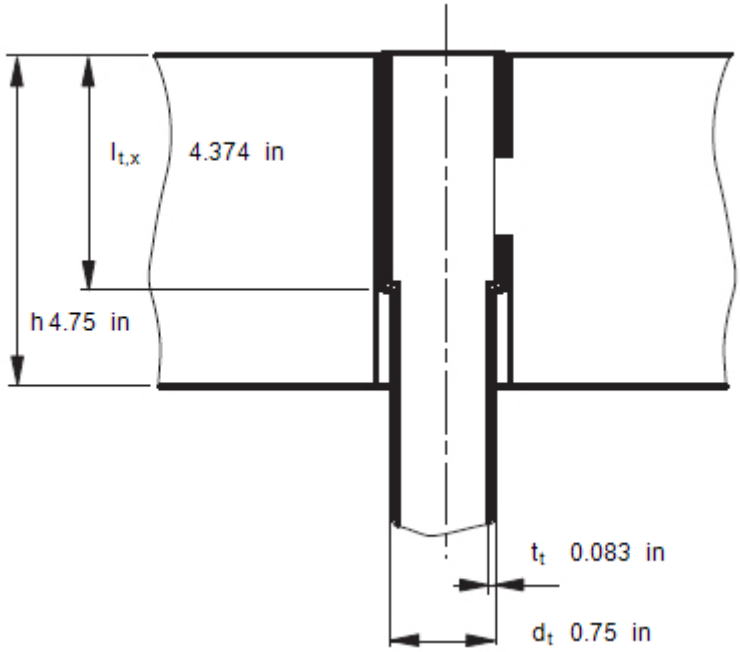
Properties for testing at 20°C

Strength *)	33939	psi	23496	psi	33939	psi
Safety factor	1		1		1	
Yield strength	37710	psi	26107	psi	37710	psi
Tensile strength	70343	psi	47137	psi	70343	psi

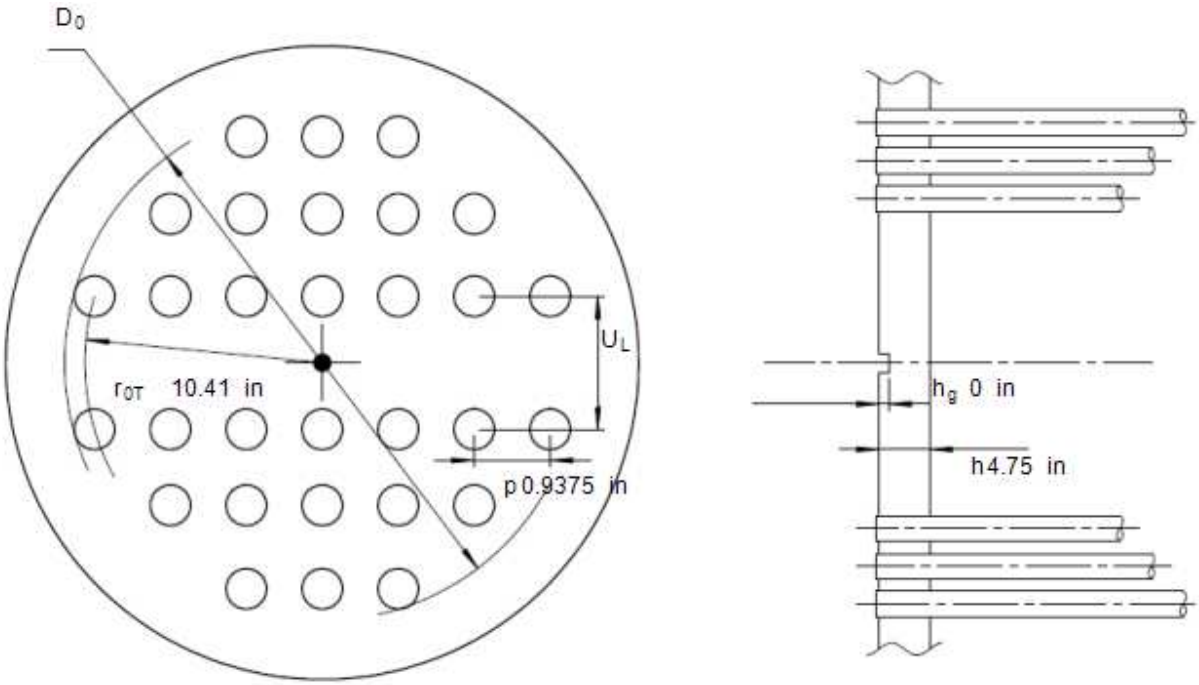
Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*434*	



Expanded length of tube in tubesheet		$l_{t,x}$	*4.374*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*10.41*	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	*0.9375*	in



Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*135.1*	in
Unsupported tube span for buckling	l		in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k		
Equivalent free buckling length k·l	l_t	*34*	in
Bellows inside diameter at its convolution height	D_j	*29.46*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*14759*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	-

Material properties for mean operation temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*490*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.28*	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material	*K02700-SA-516-70-Class:-Size:*			
Increased shell thickness with allowances		t_{1s}	*1.25*	in
Thickness allowance		c_{1s}	0	in
Corrosion allowance		c_{2s}	*0.125*	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)		l_1	*9.875*	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)		l'_1	*9.875*	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$		l_{min}	**9.206**	in
Yield strength of shell at T_s =	**675** °F	S_{y1s}	*27741*	psi
Strength of shell at T_s		K_{1s}	18355	psi
Safety factor of shell at T_s		S_{s1}	1	
Allowable stress for shell at T_s		S_{1s}	*18355*	psi
Tensile strength at room temperature 20°C		S_{z1s}	70343	psi
Limit temperature for time dependent properties		T_{G1s}	752	°F
Allowable primary and secondary stress at T_s		S_{ps1s}	*55482*	psi
E-Modulus of shell at T_s		E_{1s}	*2.579e+7*	psi
Mean coefficient of thermal expansion at T_{sm}		α_{sm1}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*30.12*	in
Number of bolts	n	*28*	-
Bolt root diameter	d_B	*1.213*	in
Total bolt area	A_b	**32.36**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	*1*	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	*26.13*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.25*	in
Gasket factor (Table 2-5.1)	m			*6.5*	
Gasket seating pressure	Y		psi	*26000*	psi
Diameter of gasket force	G		in	***25.63***	in
Poisson's ratio	v	*0.3*		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**806110**	lbf
Total req. bolt root area	A_m	**0**	in²	**32.31**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.709**	in

Maximum bolt force for all calculation cases	W_{max}	*808478*	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**806655**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.002501**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.375**	in
Shell inside diameter corroded (type abc)	D_s	**23.25**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.6397**	in
Effective pitch	p*	**0.9375**	in
Effective ligament efficiency for shear	μ*	**0.3176**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**10.78**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**12.81**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**11.62**	in
Ratio = ac/a0	ρ_C	**1.189**	
Ratio = as/a0	ρ_S	**1.078**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4749**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6816**	
Type abc: Coefficients for shell pressure	δ_S	**0.01458**	mm^3/N
β_S **4.166** 1/ft k_S **2335050** lbf	λ_S	**1.352e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	**5886426**	lbf/in
Tube axial rigidity	K_t	**33564**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.4041**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.002501**	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	**7782575**	psi
Ratio of elasticity tubesheet	E*/E	**0.3043**	
effective Poisson's ratio tubesheet	v*	**0.3427**	
Parameter for table UHX-13.1	X_a	**2.003**	
Z_d **0.1725** Z_v **0.1602** Z_m **0.6667** Z_a **0.8146**	Z_w	**0.1602**	

Step 4

Diameter ratio = A/D0	K	**1.525**	
F **2.053** Φ **2.757**	Q_1	**-0.128**	
Q_{z1} **1.223** Q_{z2} **0.6023**	U	**1.205**	

UHX-13.5.5 Step 5, coefficients

γ(*) **-0.06033** in	ω_S	**8.865** in²	ω_S* **-8.495** in²
ω_C **0** in²	ω_C*	**8.674** in²	γ_b **-0.2085**

Results acc. UHX-13.8 Radial differential thermal expansion

T_r **68** °F	T_s*	**68** °F	T_c* **68** °F
P_s* **0** psi	P_c*	**0** psi	P_ω **0** psi

Step 6

P_s' **0** psi	P_t'	**1029949** psi	P_γ **-2407** psi
P_W **278.1** psi	P_{rim}	**93.49** psi	P_e **-1042** psi

UHX-13.5.7 Step 7

Q_2 **-12634** lbf	Q_3	**0.08071**	F_m **0.1977**

Strength condition for the tubesheet bending stress, case 5

σ = **22328** psi	< 1.5 · σ_B	= 1.5·	*18450*	psi	case 1-3
	< S_{PS}	=	*55481*	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14760** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 *Y* **)**

F_{tmin}	**0.4536**		F_{tmax}	**1.492**	
x_{min}	**0**		x_{max}	**2.003**	
$\sigma_{T,1}$	**-1144**	psi	$\sigma_{T,2}$	**4090**	psi

σ_{tmax} = **4090** psi ≤ σ_T = *12588* psi for calculation case 1-3

≤2 · σ_T = **25176** psi for calculation case 4-7

Tube weld force W_t = **711.4** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	**0.2376**	in	F_t	**143.1**	C_t	**2**	F_s	**163.3**

$|\sigma_{tmin}|$ = | **-1144** psi | ≤S_{tb} = **5423** psi (only σ_{tmin} < 0 buckl.)

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.5* in : (calculation case)

σ_{Sm} ≤ *1*· ***18355*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-21.47** psi ≤2· ***18355*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-21.47**	psi |	< Min(	**10757**	psi	, **50379**	psi	)

ASME external pressure chart CS-2 A = **0.003906**

Region of increased thickness t_{1s} = *1.25* in : (calculation case)

σ_{Sm} ≤ *1*· *18355* psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-6.937** psi ≤2· *18355* psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-6.937**	psi |	< Min(	**12539**	psi	, **142247**	psi	)

ASME external pressure chart CS-2 A = **0.01103**

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **41124** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-6.937** psi | + | **-41117** psi | ≤ **55482** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3	
Shell	**2.579e+7** psi	**2.579e+7** psi	
Channel	psi	psi	

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:

σ_S = **41124** psi ≤ ***55481*** psi $=S_{PSs}$

with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:

σ_C = **0** psi ≤ *0* psi $=S_{PSc}$

Geometric conditions:

valid

Strength condition for linked modules (Connection activated: No):

13.4(d) If: Tube sheet thickness= *4.75* in < *0.75* in

= Tube outside diameter, the tubesheet deformation must be considered.

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· ***18355*** psi or 2· *27741* psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1030898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5878\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{176335\ \text{MPa}} \cdot \frac{86.79\ \text{MPa}}{127.2\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.25\ \text{mm}}{16.25\ \text{mm}} = 0.3176$$

6 E4.18.6 O2
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	*b*		(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)		*1*		(1,2)
Internal operation pressure shell side	P_s	*335*	psi	
Internal operation pressure tube side	P_t	*1040*	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 per UHX-13.4(a): (1-D1), (2-D2), (3-D3)		6		(1-3)
Calculation case per UHX-13.4(a): (4-O4),(5-O1), (6-O2), (7-O3)		6		(4-7)
Shell side pressure only (Pt=0) with differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*675*	°F	*650*	°F	*675*	°F
Thickness		*4.75*	in	*0.083*	in	*0.5*	in
Outside diameter		*32.88*	in	*0.75*	in	*24*	in
Poisson's ratio	-			*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0.25*	in	*0*	in	*0.125*	in

Properties for the selected load case temperature

Strength operat.	18355	psi	10927	psi	18355	psi
Safety operation	1		1		1	
Young's modulus	*2.558e+7*	psi	*2.608e+7*	psi	*2.579e+7*	psi
Thermal expansion	*7.548*	1E-6/°F	*7.509*	1E-6/°F	*7.548*	1E-6/°F
Yield strength	*27741*	psi	*19300*	psi	*27741*	psi
Limit temperature	752	°F	752	°F	752	°F
Allow. stress	*18450*	psi	*12588*	psi	***18355***	psi
Prim.+sec. str.	*55481*	psi			***55481***	psi

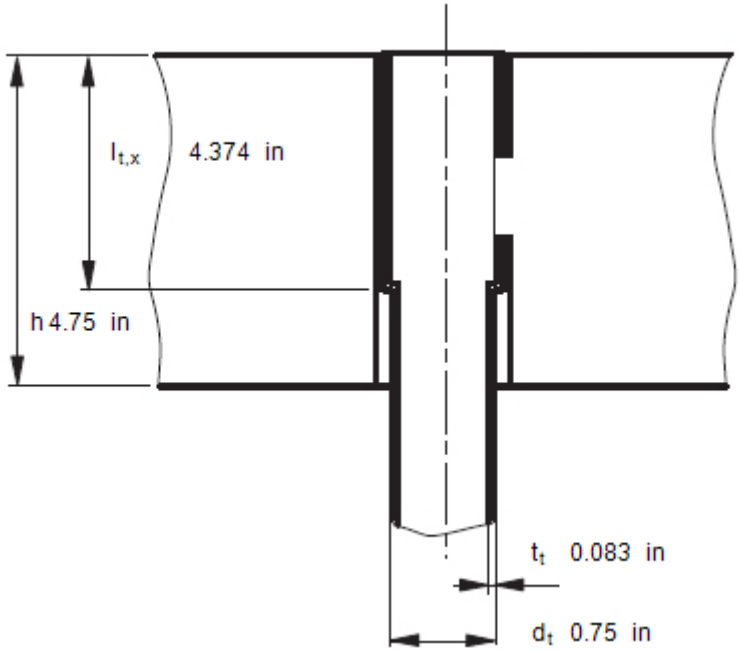
Properties for testing at 20°C

Strength *)	33939	psi	23496	psi	33939	psi
Safety factor	1		1		1	
Yield strength	37710	psi	26107	psi	37710	psi
Tensile strength	70343	psi	47137	psi	70343	psi

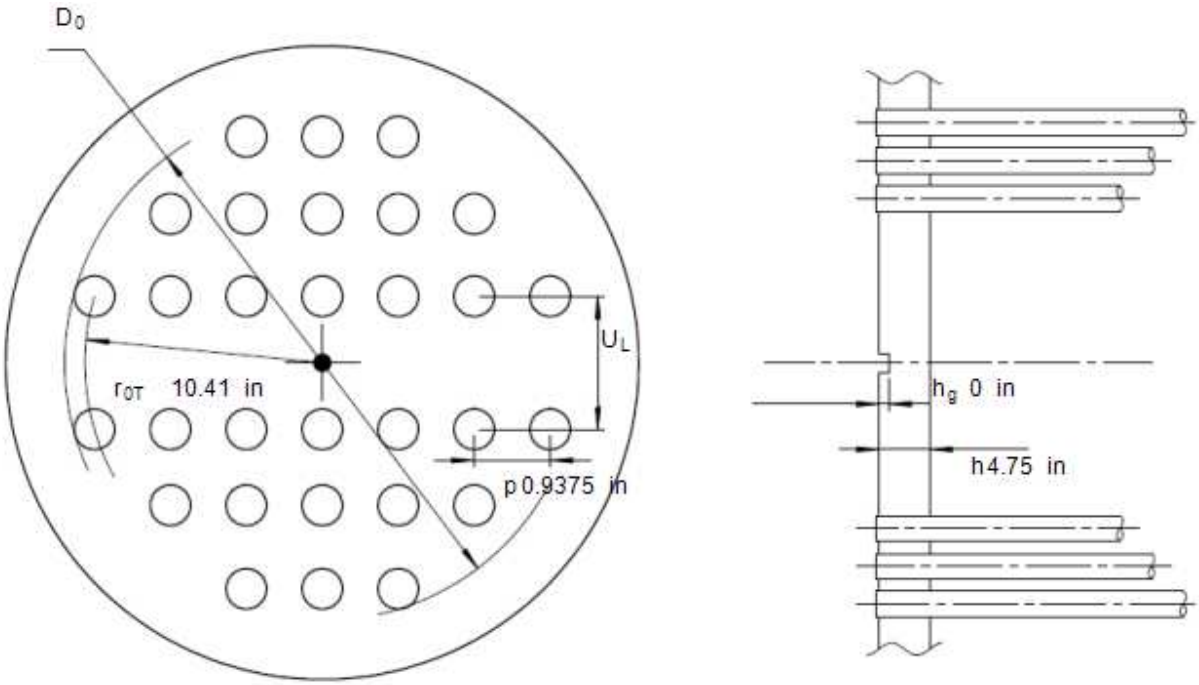
Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*434*	



Expanded length of tube in tubesheet		$l_{t,x}$	*4.374*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*10.41*	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	*0.9375*	in



Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*135.1*	in
Unsupported tube span for buckling	l		in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k		
Equivalent free buckling length k·l	l_t	*34*	in
Bellows inside diameter at its convolution height	D_j	*29.46*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*14759*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	-

Material properties for mean operation temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*490*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.28*	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material *K02700-SA-516-70-Class:-Size:*

Increased shell thickness with allowances	t_{1s}	*1.25*	in
Thickness allowance	c_{1s}	0	in
Corrosion allowance	c_{2s}	*0.125*	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)	l_1	*9.875*	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)	l'_1	*9.875*	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$	l_{min}	**9.206**	in
Yield strength of shell at T_s = **675** °F	S_{y1s}	*27741*	psi
Strength of shell at T_s	K_{1s}	18355	psi
Safety factor of shell at T_s	S_{s1}	1	
Allowable stress for shell at T_s	S_{1s}	*18355*	psi
Tensile strength at room temperature 20°C	S_{z1s}	70343	psi
Limit temperature for time dependent properties	T_{G1s}	752	°F
Allowable primary and secondary stress at T_s	S_{ps1s}	*55482*	psi
E-Modulus of shell at T_s	E_{1s}	*2.579e+7*	psi
Mean coefficient of thermal expansion at T_{sm}	α_{sm1}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*30.12*	in
Number of bolts	n	*28*	-
Bolt root diameter	d_B	*1.213*	in
Total bolt area	A_b	**32.36**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	*1*	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	*26.13*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.25*	in
Gasket factor (Table 2-5.1)	m			*6.5*	
Gasket seating pressure	Y		psi	*26000*	psi
Diameter of gasket force	G		in	***25.63***	in
Poisson's ratio	v	*0.3*		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.8**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.709**	in

Maximum bolt force for all calculation cases	W_{max}	*808478*	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**663079**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.002501**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.375**	in
Shell inside diameter corroded (type abc)	D_s	**23.25**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.6397**	in
Effective pitch	p*	**0.9375**	in
Effective ligament efficiency for shear	μ*	**0.3176**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**10.78**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**12.81**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**11.62**	in
Ratio = ac/a0	ρ_C	**1.189**	
Ratio = as/a0	ρ_S	**1.078**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4749**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6816**	
Type abc: Coefficients for shell pressure	δ_S	**0.01458**	mm^3/N
β_S **4.166** 1/ft k_S **2335050** lbf	λ_S	**1.352e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	**5886426**	lbf/in
Tube axial rigidity	K_t	**33564**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.4041**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.002501**	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	**7782575**	psi
Ratio of elasticity tubesheet	E*/E	**0.3043**	
effective Poisson's ratio tubesheet	v*	**0.3427**	
Parameter for table UHX-13.1	X_a	**2.003**	
Z_d **0.1725** Z_v **0.1602** Z_m **0.6667** Z_a **0.8146**	Z_w	**0.1602**	

Step 4

Diameter ratio = A/D0	K	**1.525**	
F **2.053** Φ **2.757**	Q_1	**-0.128**	
Q_{z1} **1.223** Q_{z2} **0.6023**	U	**1.205**	

UHX-13.5.5 Step 5, coefficients

γ(*) **-0.06033** in ω_S **8.865** in²	ω_S*	**-8.495**	in²
ω_C **0** in² ω_C* **8.674** in²	γ_b	**-0.2085**	

Results acc. UHX-13.8 Radial differential thermal expansion

T_r **68** °F T_s* **68** °F	T_c*	**68**	°F
P_s* **0** psi P_c* **0** psi	P_ω	**0**	psi

Step 6

P_s' **-169482** psi P_t' **0** psi	P_γ	**-2407**	psi
P_W **278.1** psi P_{rim} **29.49** psi	P_e	**-173.2**	psi

UHX-13.5.7 Step 7

Q_2 **-10457** lbf Q_3 **0.911**	F_m	**0.5316**	

Strength condition for the tubesheet bending stress, case 6

σ = **9983** psi	< 1.5 · σ_B	= 1.5·	*18450*	psi	case 1-3
	< S_{PS}	=	*55481*	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14760** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 *Y* **)**

F_{tmin}	**-0.5591**		F_{tmax}	**2.563**	
x_{min}	**0**		x_{max}	**2.003**	
$\sigma_{T,1}$	**301.2**	psi	$\sigma_{T,2}$	**2917**	psi

σ_{tmax} = **2917** psi ≤ σ_T = *12588* psi for calculation case 1-3

≤2 · σ_T = **25176** psi for calculation case 4-7

Tube weld force W_t = **507.3** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	**0.2376**	in	F_t	**143.1**	C_t	**1.969**	F_s	**163.3**

$|\sigma_{tmin}|$ = | **301.2** psi | ≤S_{tb} = **5509** psi (only σ_{tmin} < 0 buckl.)

Strength acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.5* in : (calculation case)

σ_{Sm} ≤ *1*· ***18355*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-1557** psi ≤2· ***18355*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-1557**	psi	| < Min(	**10757**	psi	, **50379**	psi	)

ASME external pressure chart CS-2 A = **0.003906**

Region of increased thickness t_{1s} = *1.25* in : (calculation case)

σ_{Sm} ≤ *1*· *18355* psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-503** psi ≤2· *18355* psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-503**	psi	| < Min(	**12539**	psi	, **142247**	psi	)

ASME external pressure chart CS-2 A = **0.01103**

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **19929** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-503** psi | + | **-19426** psi | ≤ **55482** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3	
Shell	**2.579e+7** psi	**2.579e+7** psi	
Channel	psi	psi	

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:
σ_S = **19929** psi ≤ ***55481*** psi $=S_{PSs}$
with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:
σ_C = **0** psi ≤ *0* psi $=S_{PSc}$

Geometric conditions:
valid

Strength condition for linked modules (Connection activated: No):
13.4(d) If: Tube sheet thickness= *4.75* in < *0.75* in
= Tube outside diameter, the tubesheet deformation must be considered.
UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· ***18355*** psi or 2· *27741* psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1030898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5878\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{176335\ \text{MPa}} \cdot \frac{86.79\ \text{MPa}}{127.2\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.25\ \text{mm}}{16.25\ \text{mm}} = 0.3176$$

7 E4.18.6 O3
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	*b*		(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)		*1*		(1,2)
Internal operation pressure shell side	P_s	*335*	psi	
Internal operation pressure tube side	P_t	*1040*	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 per UHX-13.4(a): (1-D1), (2-D2), (3-D3)		7		(1-3)
Calculation case per UHX-13.4(a): (4-O4),(5-O1), (6-O2), (7-O3)		7		(4-7)
Tube and shell side pressure acting with differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*675*	°F	*650*	°F	*675*	°F
Thickness		*4.75*	in	*0.083*	in	*0.5*	in
Outside diameter		*32.88*	in	*0.75*	in	*24*	in
Poisson's ratio	-			*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0.25*	in	*0*	in	*0.125*	in

Properties for the selected load case temperature

Strength operat.	18355	psi	10927	psi	18355	psi
Safety operation	1		1		1	
Young's modulus	*2.558e+7*	psi	*2.608e+7*	psi	*2.579e+7*	psi
Thermal expansion	*7.548*	1E-6/°F	*7.509*	1E-6/°F	*7.548*	1E-6/°F
Yield strength	*27741*	psi	*19300*	psi	*27741*	psi
Limit temperature	752	°F	752	°F	752	°F
Allow. stress	*18450*	psi	*12588*	psi	***18355***	psi
Prim.+sec. str.	*55481*	psi			***55481***	psi

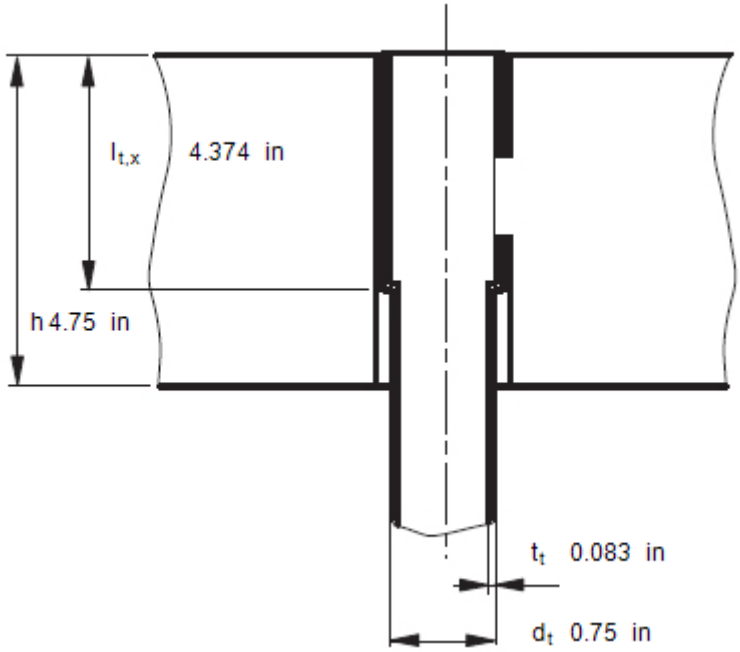
Properties for testing at 20°C

Strength *)	33939	psi	23496	psi	33939	psi
Safety factor	1		1		1	
Yield strength	37710	psi	26107	psi	37710	psi
Tensile strength	70343	psi	47137	psi	70343	psi

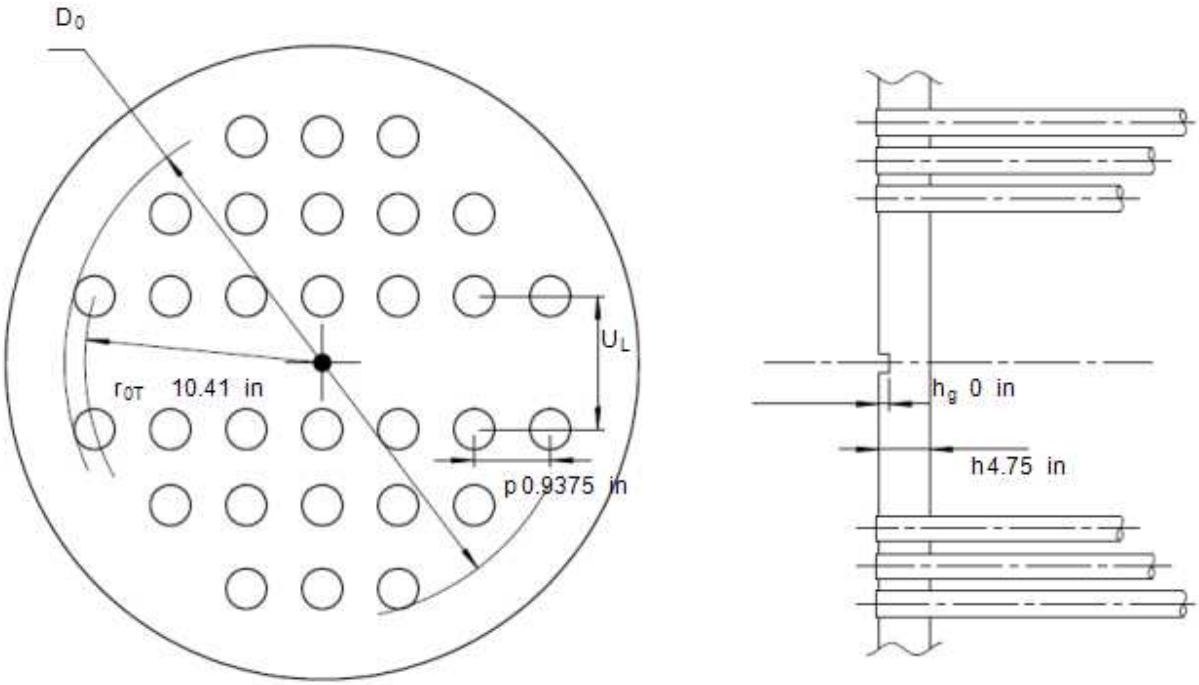
Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*434*	



Expanded length of tube in tubesheet		$l_{t,x}$	*4.374*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*10.41*	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	*0.9375*	in



Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*135.1*	in
Unsupported tube span for buckling	l		in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k		
Equivalent free buckling length k·l	l_t	*34*	in
Bellows inside diameter at its convolution height	D_j	*29.46*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*14759*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	-
Material properties for mean operation temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*490*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.28*	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material	*K02700-SA-516-70-Class:-Size:*		
Increased shell thickness with allowances	t_{1s}	*1.25*	in
Thickness allowance	c_{1s}	*0*	in
Corrosion allowance	c_{2s}	*0.125*	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)	l_1	*9.875*	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)	l'_1	*9.875*	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$	l_{min}	**9.206**	in
Yield strength of shell at T_s = **675** °F	S_{y1s}	*27741*	psi
Strength of shell at T_s	K_{1s}	18355	psi
Safety factor of shell at T_s	S_{s1}	1	
Allowable stress for shell at T_s	S_{1s}	*18355*	psi
Tensile strength at room temperature 20°C	S_{z1s}	70343	psi
Limit temperature for time dependent properties	T_{G1s}	752	°F
Allowable primary and secondary stress at T_s	S_{ps1s}	*55482*	psi
E-Modulus of shell at T_s	E_{1s}	*2.579e+7*	psi
Mean coefficient of thermal expansion at T_{sm}	α_{sm1}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*30.12*	in
Number of bolts	n	*28*	-
Bolt root diameter	d_B	*1.213*	in
Total bolt area	A_b	**32.36**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	*1*	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	*26.13*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.25*	in
Gasket factor (Table 2-5.1)	m			*6.5*	
Gasket seating pressure	Y		psi	*26000*	psi
Diameter of gasket force	G		in	***25.63***	in
Poisson's ratio	v	*0.3*		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**806110**	lbf
Total req. bolt root area	A_m	**0**	in²	**32.31**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.709**	in

Maximum bolt force for all calculation cases	W_{max}	*808478*	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**806655**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.002501**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.375**	in
Shell inside diameter corroded (type abc)	D_s	**23.25**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.6397**	in
Effective pitch	p*	**0.9375**	in
Effective ligament efficiency for shear	μ*	**0.3176**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**10.78**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**12.81**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**11.62**	in
Ratio = ac/a0	ρ_C	**1.189**	
Ratio = as/a0	ρ_S	**1.078**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4749**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6816**	
Type abc: Coefficients for shell pressure	δ_S	**0.01458**	mm^3/N
β_S **4.166** 1/ft k_S **2335050** lbf	λ_S	**1.352e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	**5886426**	lbf/in
Tube axial rigidity	K_t	**33564**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.4041**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.002501**	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	**7782575**	psi
Ratio of elasticity tubesheet	E*/E	**0.3043**	
effective Poisson's ratio tubesheet	v*	**0.3427**	
Parameter for table UHX-13.1	X_a	**2.003**	
Z_d **0.1725** Z_v **0.1602** Z_m **0.6667** Z_a **0.8146**	Z_w	**0.1602**	

Step 4

Diameter ratio = A/D0	K	**1.525**	
F **2.053** Φ **2.757**	Q_1	**-0.128**	
Q_{z1} **1.223** Q_{z2} **0.6023**	U	**1.205**	

UHX-13.5.5 Step 5, coefficients

γ(*) **-0.06033** in	ω_S	**8.865** in²	ω_S* **-8.495** in²
ω_C **0** in²	ω_C*	**8.674** in²	γ_b **-0.2085**

Results acc. UHX-13.8 Radial differential thermal expansion

T_r **68** °F	T_s*	**68** °F	T_c* **68** °F
P_s* **0** psi	P_c*	**0** psi	P_ω **0** psi

Step 6

P_s' **-169482** psi	P_t'	**1029949** psi	P_γ **-2407** psi
P_W **278.1** psi	P_{rim}	**123** psi	P_e **-1213** psi

UHX-13.5.7 Step 7

Q_2 **-13636** lbf	Q_3 **0.0655**		F_m **0.1919**
Strength condition for the tubesheet bending stress, case		7	

σ = **25238** psi	< 1.5 · σ_B	= 1.5·	*18450* psi	case 1-3
	< S_{PS}	=	*55481* psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14760** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 *Y* **)**

F_{tmin}	**0.4722**		F_{tmax}	**1.473**	
x_{min}	**0**		x_{max}	**2.003**	
$\sigma_{T,1}$	**110.2**	psi	$\sigma_{T,2}$	**5980**	psi

σ_{tmax} = **5980** psi ≤ σ_T = *12588* psi for calculation case 1-3

≤2 · σ_T = **25176** psi for calculation case 4-7

Tube weld force W_t = **1040** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	**0.2376**	in	F_t	**143.1**	C_t	**2**	F_s	**163.3**

$|\sigma_{tmin}|$ = | **110.2** psi | ≤S_{tb} = **5423** psi (only σ_{tmin} < 0 buckl.)

Strength acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.5* in : (calculation case)

σ_{Sm} ≤ *1*· ***18355*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-1550** psi ≤2· ***18355*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-1550**	psi |	< Min(	**10757**	psi	, **50379**	psi	)

ASME external pressure chart CS-2 A = **0.003906**

Region of increased thickness t_{1s} = *1.25* in : (calculation case)

σ_{Sm} ≤ *1*· *18355* psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-500.9** psi ≤2· *18355* psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-500.9**	psi |	< Min(	**12539**	psi	, **142247**	psi	)

ASME external pressure chart CS-2 A = **0.01103**

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **41005** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-500.9** psi | + | **-40504** psi | ≤ **55482** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3	
Shell	**2.579e+7** psi	**2.579e+7** psi	
Channel	psi	psi	

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:
σ_S = **41005** psi ≤ ***55481*** psi $=S_{PSs}$
with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:
σ_C = **0** psi ≤ *0* psi $=S_{PSc}$

Geometric conditions:
valid

Strength condition for linked modules (Connection activated: No):
13.4(d) If: Tube sheet thickness= *4.75* in < *0.75* in
= Tube outside diameter, the tubesheet deformation must be considered.
UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· ***18355*** psi or 2· *27741* psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1030898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5878\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{176335\ \text{MPa}} \cdot \frac{86.79\ \text{MPa}}{127.2\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.25\ \text{mm}}{16.25\ \text{mm}} = 0.3176$$

8 E4.18.6 D1 plastic
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

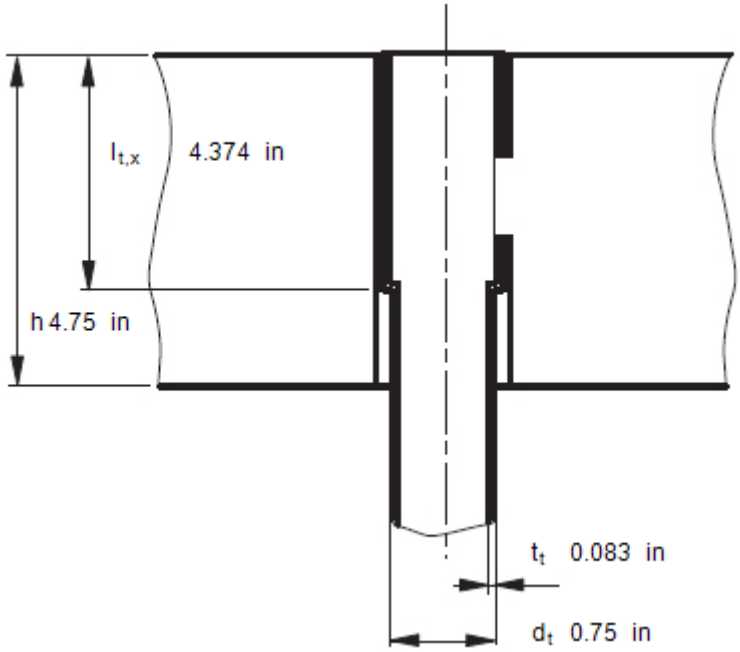
Configuration of the tubesheet (a, b, c, d)	Type	b	(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operation pressure shell side	P_s	335	psi
Internal operation pressure tube side	P_t	1040	psi
Internal test pressure 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 per UHX-13.4(a): (1-D1), (2-D2), (3-D3)		1	(1-3)
Calculation case per UHX-13.4(a): (4-O4),(5-O1), (6-O2), (7-O3)		1	(4-7)
Tube side pressure only (Ps=0) without differential thermal expansion			
Tubesheet material	K02700-SA-516-70-Class:-Size:		
Tube material	K01807-SA-214--Class:-Size:		
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:		

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		675	°F	650	°F	675	°F
Thickness		4.75	in	0.083	in	0.5	in
Outside diameter		32.88	in	0.75	in	24	in
Poisson's ratio	-			0.3		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	0.25	in	0	in	0.125	in
Properties for the selected load case temperature							
Strength operat.		18355	psi	10927	psi	18355	psi
Safety operation		1		1		1	
Young's modulus		2.579e+7	psi	2.608e+7	psi	2.579e+7	psi
Thermal expansion		7.548	1E-6/°F	7.509	1E-6/°F	7.548	1E-6/°F
Yield strength		27741	psi	19300	psi	27741	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		**18355**	psi	**10927**	psi	**18355**	psi
Prim.+sec. str.		**55481**	psi			**55481**	psi
Properties for testing at 20°C							
Strength	*)	33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

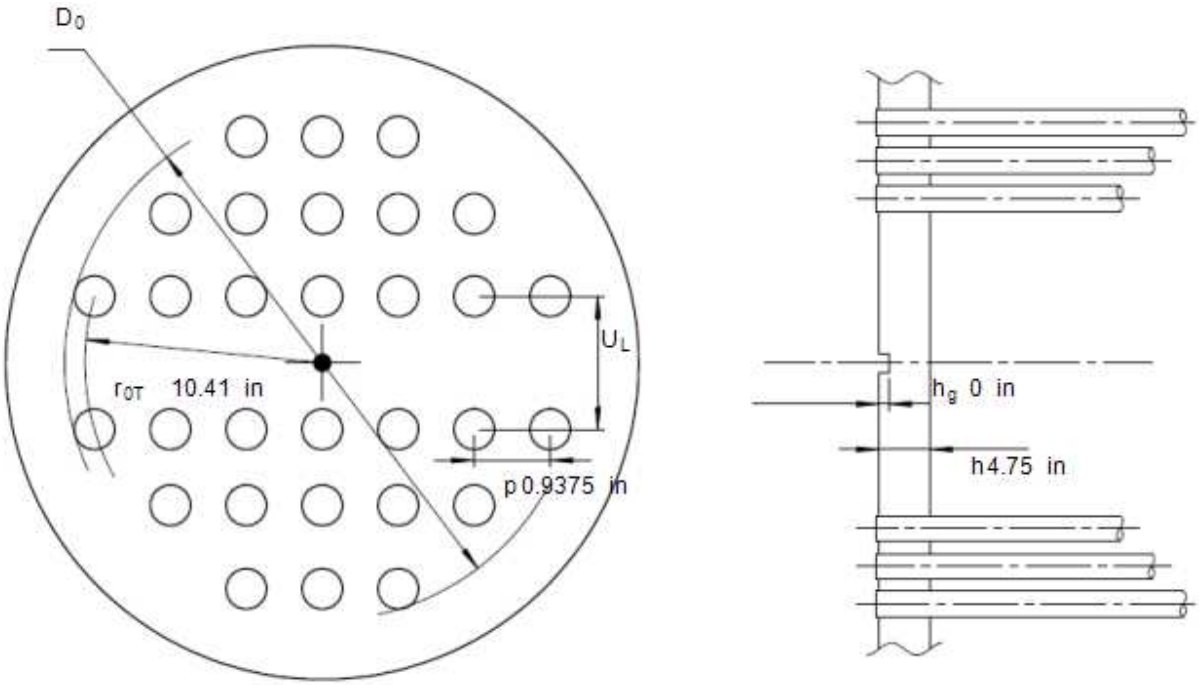
Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		1	(1, 2)
Number of tubes		N_t	434	



Expanded length of tube in tubesheet		$l_{t,x}$	4.374	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	10.41	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	0.9375	in



Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0	in²
Depth of tube side pass partition groove		h_g	0	in

Tube length between inner tubesheet faces	L	135.4	in
Unsupported tube span for buckling	l	34	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	1	
Equivalent free buckling length k·l	l_t	**34**	in
Bellows inside diameter at its convolution height	D_j	29.46	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	14759	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	1	-

Material properties for mean operation temperature

Mean temperature along the shell length	T_{sm}	550	°F
Mean temperature along the tube length	T_{tm}	490	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	7.348	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	7.237	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material K02700-SA-516-70-Class:-Size:

Increased shell thickness with allowances	t_{1s}	1.25	in
Thickness allowance	c_{1s}	0	in
Corrosion allowance	c_{2s}	0.125	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)	l_1	9.875	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)	l'_1	9.875	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$	l_{min}	**9.206**	in
Yield strength of shell at T_s = **675** °F	S_{y1s}	27741	psi
Strength of shell at T_s	K_{1s}	18355	psi
Safety factor of shell at T_s	S_{s1}	1	
Allowable stress for shell at T_s	S_{1s}	**18355**	psi
Tensile strength at room temperature 20°C	S_{z1s}	70343	psi
Limit temperature for time dependent properties	T_{G1s}	752	°F
Allowable primary and secondary stress at T_s	S_{ps1s}	**55482**	psi
E-Modulus of shell at T_s	E_{1s}	2.579e+7	psi
Mean coefficient of thermal expansion at T_{sm}	α_{sm1}	7.348	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	30.12	in
Number of bolts	n	28	-
Bolt root diameter	d_B	1.213	in
Total bolt area	A_b	**32.36**	in²
Bolt material G41400-SA-193-B7-Class:-Size:<=64			
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	1	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	26.13	in
Contact inside diameter	G_i		in	25.12	in
Basic seating width	b_0		in	0.25	in
Gasket factor (Table 2-5.1)	m			6.5	
Gasket seating pressure	Y		psi	26000	psi
Diameter of gasket force	G		in	**25.63**	in
Poisson's ratio	v	0.3		0.3	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**806110**	lbf
Total req. bolt root area	A_m	**0**	in²	**32.31**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.706**	in

Maximum bolt force for all calculation cases	W_{max}	806655	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		Y	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	806655	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	0.002506	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	0.375	in
Shell inside diameter corroded (type abc)	D_s	23.25	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	0.2	
Effective tube hole diameter	d*	0.6401	in
Effective pitch	p*	0.9375	in
Effective ligament efficiency for shear	μ*	0.3172	
Effective depth of pass partition groove	h_g'	0	in
Equivalent radius of outer tube limit circle	a_0	10.78	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	12.81	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	11.62	in
Ratio = ac/a0	ρ_C	1.189	
Ratio = as/a0	ρ_S	1.078	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	0.4749	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	0.6816	
Type abc: Coefficients for shell pressure	δ_S	0.01458	mm^3/N
β_S 4.166 1/ft k_S 2335050 lbf	λ_S	1.352e+7	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	5874384	lbf/in
Tube axial rigidity	K_t	33502	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	0.404	
Stiffness ratio Kj/(Ks+Kj)	J	0.002506	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	7835734	psi
Ratio of elasticity tubesheet	E*/E	0.3038	
effective Poisson's ratio tubesheet	v*	0.3429	
Parameter for table UHX-13.1	X_a	1.999	
Z_d 0.1736 Z_v 0.1603 Z_m 0.6672 Z_a 0.8116	Z_w	0.1603	

Step 4

Diameter ratio = A/D0	K	1.525	
F 2.046 Φ 2.748	Q_1	-0.1279	
Q_{z1} 1.222 Q_{z2} 0.5985	U	1.197	

UHX-13.5.5 Step 5, coefficients

γ(*) 0 in ω_S 8.865 in²	ω_S*	-8.495	in²
ω_C 0 in² ω_C* 8.674 in²	γ_b	-0.2085	

Results acc. UHX-13.8 Radial differential thermal expansion

T_r 68 °F	T_s* 68 °F	T_c*	68 °F
P_s* 0 psi	P_c* 0 psi	P_ω	0 psi

Step 6

P_s' 0 psi	P_t' 1028053 psi	P_γ	0 psi
P_W 275.7 psi	P_{rim} 92.91 psi	P_e	-1039 psi

UHX-13.5.7 Step 7

Q_2 -12633 lbf	Q_3 0.08131	F_m	0.1983

Strength condition for the tubesheet bending stress, case 1

σ = 22374 psi	< 1.5 · σ_B	= 1.5·	18355	psi	case 1-3	
	< S_{PS}	=	55481	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14684** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 Y)

F_{tmin}	**0.4569**		F_{tmax}	**1.489**	
x_{min}	**0**		x_{max}	**1.999**	
$\sigma_{T,1}$	**-1132**	psi	$\sigma_{T,2}$	**4058**	psi

σ_{tmax} = **4058** psi ≤ σ_T = **10927** psi for calculation case 1-3

≤2 · σ_T = **21854** psi for calculation case 4-7

Tube weld force W_t = **705.8** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	**0.2376**	in	F_t	**143.1**		C_t	**2**	F_s	**163.3**

$|\sigma_{tmin}|$ = | **-1132** psi | ≤S_{tb} = **5423** psi (only σ_{tmin} < 0 buckl.)

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = 0.5 in : (calculation case)

σ_{Sm} ≤ 1· **18355** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **10.35** psi ≤2· **18355** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**10.35** psi	| < Min(	**10757** psi	,	**50379** psi	)		
ASME external pressure chart		CS-2		A	=	**0.003906**		

Region of increased thickness t_{1s} = 1.25 in : (calculation case)

σ_{Sm} ≤ 1· **18355** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **3.345** psi ≤2· **18355** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**3.345** psi	| < Min(	**12539** psi	,	**142247** psi	)		
ASME external pressure chart		CS-2		A	=	**0.01103**		

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **40854** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **3.345** psi | + | **-40850** psi | ≤ **27533** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is violated!

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3	
Shell	**2.579e+7** psi	**2.579e+7** psi	
Channel	psi	psi	

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:

σ_S = **40854** psi ≤ **55481** psi $=S_{PSs}$

with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:

σ_C = **0** psi ≤ **0** psi $=S_{PSc}$

Geometric conditions:

valid

Strength condition for linked modules (Connection activated: Yes):

Strength violated for calculation case: 1 3

13.4(d) If: Tube sheet thickness= 4.75 in < 0.75 in

= Tube outside diameter, the tubesheet deformation must be considered.

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· **18355** psi or 2· 27741 psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1028789\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5867\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{177844\ \text{MPa}} \cdot \frac{75.34\ \text{MPa}}{126.6\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.26\ \text{mm}}{16.26\ \text{mm}} = 0.3172$$

9 E4.18.6 D3 plastic
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

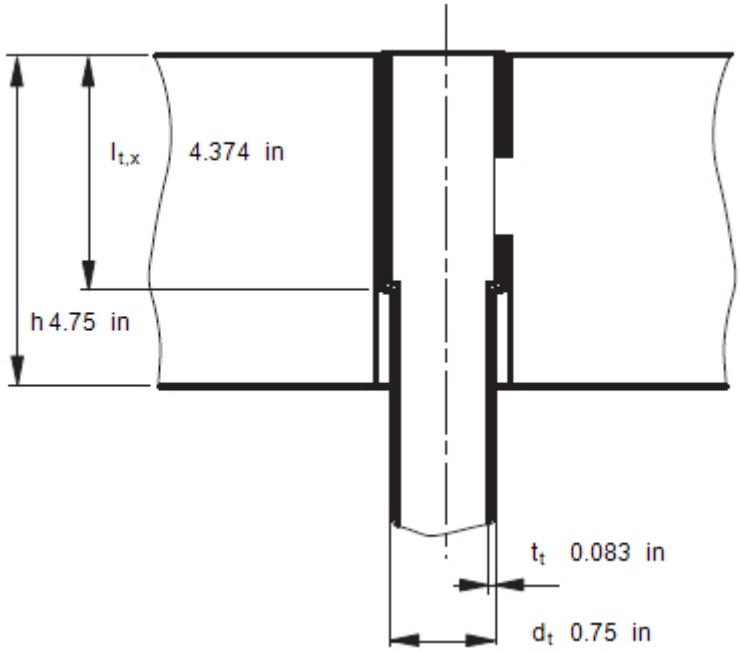
Configuration of the tubesheet (a, b, c, d)		Type	b	(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)			1	(1,2)
Internal operation pressure shell side		P_s	335	psi
Internal operation pressure tube side		P_t	1040	psi
Internal test 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 per UHX-13.4(a):	(1-D1), (2-D2), (3-D3)		3	(1-3)
Calculation case per UHX-13.4(a):	(4-O4),(5-O1), (6-O2), (7-O3)		3	(4-7)
Tube and shell side pressure acting without differential thermal expansion				
Tubesheet material	K02700-SA-516-70-Class:-Size:			
Tube material	K01807-SA-214--Class:-Size:			
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		675	°F	650	°F	675	°F
Thickness		4.75	in	0.083	in	0.5	in
Outside diameter		32.88	in	0.75	in	24	in
Poisson's ratio	-			0.3		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	0.25	in	0	in	0.125	in
Properties for the selected load case temperature							
Strength operat.		18355	psi	10927	psi	18355	psi
Safety operation		1		1		1	
Young's modulus		2.579e+7	psi	2.608e+7	psi	2.579e+7	psi
Thermal expansion		7.548	1E-6/°F	7.509	1E-6/°F	7.548	1E-6/°F
Yield strength		27741	psi	19300	psi	27741	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		18355	psi	12588	psi	18355	psi
Prim.+sec. str.		55481	psi			55481	psi
Properties for testing at 20°C							
Strength	*)	33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

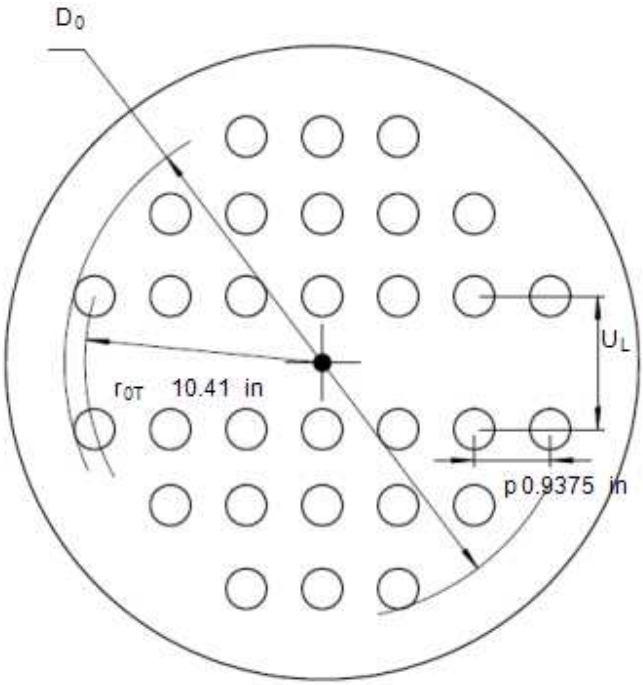
Additional specifications for the geometry and loading

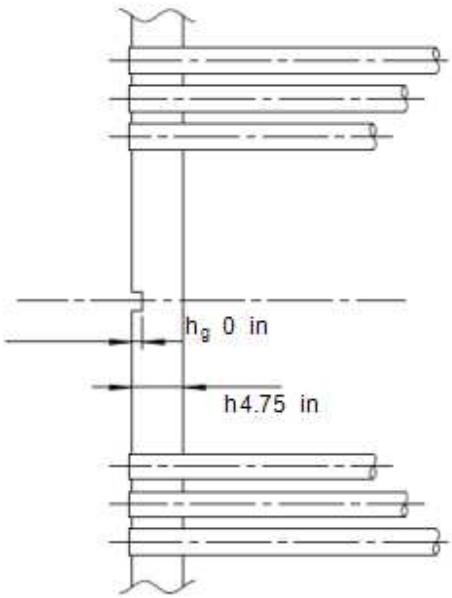
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		1	(1, 2)
Number of tubes		N_t	434	



Expanded length of tube in tubesheet		$l_{t,x}$	4.374	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.972**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	10.41	in
Perimeter of the outermost tubes	UHX-12.2	C_p		in
Total area enclosed by C_p	UHX-12.2	A_p		in²
Tube pitch (center distance)		p	0.9375	in





Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0	in²
Depth of tube side pass partition groove		h_g	0	in

Tube length between inner tubesheet faces	L	135.4	in
Unsupported tube span for buckling	l		in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k		
Equivalent free buckling length k·l	l_t	34	in
Bellows inside diameter at its convolution height	D_j	29.46	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	14759	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	1	-
Material properties for mean operation temperature			
Mean temperature along the shell length	T_{sm}	550	°F
Mean temperature along the tube length	T_{tm}	490	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	7.348	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	7.237	1E-6/°F

UHX-13.6: Specification of values only for variable shell thickness of type abc for the shell region close to the

Shell material	K02700-SA-516-70-Class:-Size:			
Increased shell thickness with allowances		t_{1s}	1.25	in
Thickness allowance		c_{1s}	0	in
Corrosion allowance		c_{2s}	0.125	in
Length of thickness t_{1s} (tubesheet1, l_1 = 0: none)		l_1	9.875	in
Length of thickness t_{1s} (tubesheet2, l'_1 = 0: none)		l'_1	9.875	in
Required length of incr. thickness $1.8\cdot\sqrt{(D_s\cdot t_{1s})}$		l_{min}	**9.206**	in
Yield strength of shell at T_s = **675** °F		S_{y1s}	27741	psi
Strength of shell at T_s		K_{1s}	18355	psi
Safety factor of shell at T_s		S_{s1}	1	
Allowable stress for shell at T_s		S_{1s}	18355	psi
Tensile strength at room temperature 20°C		S_{z1s}	70343	psi
Limit temperature for time dependent properties		T_{G1s}	752	°F
Allowable primary and secondary stress at T_s		S_{ps1s}	55482	psi
E-Modulus of shell at T_s		E_{1s}	2.579e+7	psi
Mean coefficient of thermal expansion at T_{sm}		α_{sm1}	7.348	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	30.12	in
Number of bolts	n	28	-
Bolt root diameter	d_B	1.213	in
Total bolt area	A_b	**32.36**	in²
Bolt material G41400-SA-193-B7-Class:-Size:<=64			
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	-
Safety for test	S_{sp}	1	-
Stress intensification factor for testing (see App.S)	F_s	1	-

Gasket		**Shell Type d**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in	26.13	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	0.25	in
Gasket factor (Table 2-5.1)	m			6.5	
Gasket seating pressure	Y		psi	26000	psi
Diameter of gasket force	G		in	**25.63**	in
Poisson's ratio	v	0.3		0.3	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.248**	in
Gasket operating force	W	**0**	lbf	**806110**	lbf
Total req. bolt root area	A_m	**0**	in²	**32.31**	in²
A_m < actual bolt area = 20876 mm²					
Tubesheet flange thickness	h_r	**0**	in	**2.706**	in

Maximum bolt force for all calculation cases	W_{max}	806655	lbf

Results acc. UHX-13

Apply actual version UHX-13.5 (Y) or UHX-20.2:2008 (N)		Y	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	806655	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	0.002506	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	0.375	in
Shell inside diameter corroded (type abc)	D_s	23.25	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.579e+7	psi
Tube material allowable stress basis at T	K_{tT}	12500	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	0.2	
Effective tube hole diameter	d*	0.6401	in
Effective pitch	p*	0.9375	in
Effective ligament efficiency for shear	μ*	0.3172	
Effective depth of pass partition groove	h_g'	0	in
Equivalent radius of outer tube limit circle	a_0	10.78	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	12.81	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	11.62	in
Ratio = ac/a0	ρ_C	1.189	
Ratio = as/a0	ρ_S	1.078	
Parameter = 1-N_t·(0.5·d_aTUBE/a_0)^2	x_s	0.4749	
Parameter = 1-N_t·(0.5·d_iTUBE/a_0)^2	x_t	0.6816	
Type abc: Coefficients for shell pressure	δ_S	0.01458	mm^3/N
β_S 4.166 1/ft k_S 2335050 lbf	λ_S	1.352e+7	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	5874384	lbf/in
Tube axial rigidity	K_t	33502	lbf/in
Stiffness ratio K_s/(N_t·K_t)	K_{st}	0.404	
Stiffness ratio Kj/(Ks+Kj)	J	0.002506	

Step 3

Effective modulus of el. tubesheet UHX-11.3	E*	7835734	psi
Ratio of elasticity tubesheet	E*/E	0.3038	
effective Poisson's ratio tubesheet	v*	0.3429	
Parameter for table UHX-13.1	X_a	1.999	
Z_d 0.1736 Z_v 0.1603 Z_m 0.6672 Z_a 0.8116	Z_w	0.1603	

Step 4

Diameter ratio = A/D0	K	1.525	
F 2.046 Φ 2.748	Q_1	-0.1279	
Q_{z1} 1.222 Q_{z2} 0.5985	U	1.197	

UHX-13.5.5 Step 5, coefficients

γ(*) 0 in ω_S 8.865 in²	ω_S*	-8.495	in²
ω_C 0 in² ω_C* 8.674 in²	γ_b	-0.2085	

Results acc. UHX-13.8 Radial differential thermal expansion

T_r 68 °F	T_s* 68 °F	T_c*	68 °F
P_s* 0 psi	P_c* 0 psi	P_ω	0 psi

Step 6

P_s' -169168 psi	P_t' 1028053 psi	P_γ	0 psi
P_W 275.7 psi	P_{rim} 122.2 psi	P_e	-1210 psi

UHX-13.5.7 Step 7

Q_2 -13637 lbf	Q_3 0.06603	F_m	0.1925

Strength condition for the tubesheet bending stress, case 3

σ = 25296 psi	< 1.5 · σ_B	= 1.5·	18355	psi	case 1-3	
	< S_{PS}	=	55481	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14684** psi

Strength condition of step 7-8 are satisfied.

Step 9, acc. to actual addenda or edition of UHX-13.5.9 Y)

F_{tmin}	**0.4754**		F_{tmax}	**1.47**	
x_{min}	**0**		x_{max}	**1.999**	
$\sigma_{T,1}$	**123.7**	psi	$\sigma_{T,2}$	**5945**	psi

σ_{tmax} = **5945** psi ≤ σ_T = 12588 psi for calculation case 1-3

≤2 · σ_T = **25176** psi for calculation case 4-7

Tube weld force W_t = **1034** lbf ≤ $W_{t,all}$ = 0 lbf

(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	**0.2376**	in	F_t	**143.1**	C_t	**2**	F_s	**163.3**

$|\sigma_{tmin}|$ = | **123.7** psi | ≤S_{tb} = **5423** psi (only σ_{tmin} < 0 buckl.)

Strength acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = 0.5 in : (calculation case)

σ_{Sm} ≤ 1· 18355 psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-1518** psi ≤2· 18355 psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-1518**	psi	| < Min(	**10757**	psi	, **50379**	psi	)

ASME external pressure chart CS-2 A = **0.003906**

Region of increased thickness t_{1s} = 1.25 in : (calculation case)

σ_{Sm} ≤ 1· 18355 psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **-490.6** psi ≤2· 18355 psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)

|	**-490.6**	psi	| < Min(	**12539**	psi	, **142247**	psi	)

ASME external pressure chart CS-2 A = **0.01103**

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_S in the shell and σ_C in the channel

σ_S = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **40708** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-490.6** psi | + | **-40218** psi | ≤ **27533** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

Minimum shell length with uniform thickness l_{Sm} **9.206** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is violated!

Step 12 option 3: If the strength condition in step 11 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 permits also the reduction of the modulus of elasticity of the shell or channel.

Modulus of elasticity	elastic	Option 3	
Shell	**2.579e+7** psi	**2.579e+7** psi	
Channel	psi	psi	

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:

σ_S = **40708** psi ≤ 55481 psi $=S_{PSs}$

with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:

σ_C = **0** psi ≤ 0 psi $=S_{PSc}$

Geometric conditions:

valid

Strength condition for linked modules (Connection activated: No):

13.4(d) If: Tube sheet thickness= 4.75 in < 0.75 in

= Tube outside diameter, the tubesheet deformation must be considered.

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. UHX-13.5 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
55481 psi = 3· 18355 psi or 2· 27741 psi
(b) under the condition: SigZul not in the creep range:
T= **675** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.108\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.108\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 120.7\ \text{mm} - 0\ \text{mm} - 6.35\ \text{mm} = 114.3\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (264.3\ \text{mm} + 19.05\ \text{mm}) = 547.7\ \text{mm}$$

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

$$hg' = Max\begin{Bmatrix}(h_g - c_{2T}) \\ 0\end{Bmatrix} = Max\begin{Bmatrix}(0\ \text{mm} - 0\ \text{mm}) \\ 0\end{Bmatrix} = 0\ \text{mm}$$

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1028789\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 5867\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{111.1\ \text{mm}}{114.3\ \text{mm}} = 0.972$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{23.81\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (547.7\ \text{mm})^2}}} = 23.81\ \text{mm}$$

$$d^* = Max\begin{Bmatrix}d_1^* \\ d_2^*\end{Bmatrix}$$

$$d1^* = (d_T - 2 \cdot t_T) = (19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(19.05\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{179800\ \text{MPa}}{177844\ \text{MPa}} \cdot \frac{86.79\ \text{MPa}}{126.6\ \text{MPa}} \cdot 0.972\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{23.81\ \text{mm} - 16.26\ \text{mm}}{16.26\ \text{mm}} = 0.3172$$

10 Table
Form for equations

Tables

with comment every three lines

Gruppierung in 3 Zeilen. Zeile 3 berechnet die Differenz der ersten beiden Zeilen in %. Das Maximum jeder Zeile wird in Spalte 8 am Ende berechnet.

	Conversion factors			Step 1-3			: Maximum	
:	MPa2psi :	N2lb :	mm2in :	hr :	my* :	Kst :	J :	Diff %
1	145	0.2248	0.03937	2.709	0.3176	0.4041	0.002501	
2	0	0	0	2.704	0.3182	0.4085	0.002506	
3	0	0	0	0.1973	0.1875	1.088	0.2105	1.088

---- Step 2 ----------

	betaS :	kS :	lambdaS :	deltaS :	betaC :	kc :	lambdaC	:MaxDiff%
4	0.3471	2334946	1.352e+7	3.959e-6	0	0	0	
5	0.3471	2331037	1.35e+7	3.965e-6	0	0	0	
6	0.01233	0.1677	0.1456	0.1683	0	0	0	0.1683

---- Step 3 ----------

	ny* :	E* :	Xa :	Zd	Zv :	Zm :		:MaxDiff%
7	0.3427	7780590	2.003	0.1725	0.1602	0.6667		
8	0.3423	7803761	1.995	0.1745	0.1605	0.6679		
9	0.1069	0.2969	0.3773	1.15	0.2282	0.1716	0	1.15

---- Step 4 ----------

	K :	F :	phi :	Q1 :	Qz1 :	Qz2	U	:MaxDiff%
10	1.525	2.053	2.757	-0.128	1.223	0.6023	1.205	
11	1.525	2.047	2.747	-0.128	1.221	0.5952	1.19	
12	0.001771	0.3142	0.3473	0.007422	0.2205	1.191	1.191	1.191

---- Step 5 ----------

	omS :	om*S :	omC :	om*C :	gammab :			:MaxDiff%
13	8.865	-8.495	0	8.674	-0.2085			
14	8.865	-8.495	0	8.659	-0.2087			
15	6.204e-4	7.416e-4	0	0.1759	0.08764	0	0	0.1759

---- Step 5+6 for calculation case 7(O3)----------

	gamma :	Ps' :	Pt' :	Pgamma :	PW :	Prim :	Pe	: MaxDiff%
16	-0.06033	-169439	1029686	-2406	278	123	-1212	
17	-0.06	-167351	1017041	-2376	275	121.4	-1213	
18	0.5421	1.247	1.243	1.263	1.088	1.281	0.02754	1.281

---- Step 7+8+9 for calculation case 1 (D1)----------

	Q2 :	Q3 :	Fm :	|Sig| :	|Tau| :	Ftmin :	Sigt1	:MaxDiff%
19	-12633	0.08119	0.1979	22291		0.453	-1152	
20	-12650	0.0815	0.1986	22336		0.459	-1120	
21	0.1345	0.3752	0.3711	0.1987		1.302	2.807	2.807

---- Step 7+8+9 for calculation case 2 (D2)----------

	Q2 :	Q3 :	Fm :	|Sig| :	|Tau| :	Ftmin :	Sigt1	:MaxDiff%
22	-1003	-0.02697	0.157	2906		0.585	1253	
23	-1004	-0.027	0.1574	2913		0.59	1258	
24	0.1155	0.1099	0.2795	0.229		0.8552	0.4253	0.8552

---- Step 7+8+9 for calculation case 3 (D3)----------

	Q2 :	Q3 :	Fm :	|Sig| :	|Tau| :	Ftmin :	Sigt1(*)	: MaxDiff%
25	-13636	0.06589	0.1921	25201		0.4717	101.9	
26	-13654	0.06617	0.1927	25249		0.478	137.7	
27	0.1339	0.4251	0.3198	0.1928		1.319	26	0.4251

---- Step 7+8+9 for calculation case 4 (O4)----------

	Q2 :	Q3 :	Fm :	|Sig| :	|Tau| :	Ftmin :	Sigt1	:MaxDiff%
28	-9454	75.59	37.85	8815		-91.65	-952.3	
29	-9473	75.77	37.94	8817		-90.75	-942.9	
30	0.199	0.2332	0.2256	0.01887		0.9856	0.9972	0.9856

Links

```
1   1 UHXb: MPa2psi = 145: N2lb = 0.2248: mm2in=0.03937: #299*mm2in: #88: #198: #113
2   10 EQU: : : : 2.704: 0.3182: 0.40854: 0.0025063
3
4   1 UHXb: #121/mm2in: #122*N2lb: #123*MPa2psi: #124*mm2in^3/N2lb: #126/mm2in: #127*N2lb: #128*MPa2psi
5   10 EQU: 0.3471: 2331037: 13497065: 0.0000039653: 0: 0: 0
6
7   1 UHXb: #100: #98*MPa2psi: #120: #203: #204: #205
8   10 EQU: 0.342304: 7803761: 1.9955: 0.174495: 0.160532: 0.667867
9
10  1 UHXb: #131: #132: #206: #207: #208: #209: #210
11  10 EQU: 1.5247: 2.0466: 2.747: -0.128: 1.2206: 0.5952: 1.1904
12
13  1 UHXb: #125*mm2in^2: #136*mm2in^2: #130*mm2in^2: #135*mm2in^2: #134
14  10 EQU: 8.8648: -8.4947: 0: 8.6591: -0.2087
15

16  7 UHXb: #137*mm2in: #255*MPa2psi: #256*MPa2psi: #257*MPa2psi: #258*MPa2psi: #259*MPa2psi: #260*MPa2psi
17  10 EQU: -0.06: -167351: 1017041: -2376: 275: 121.4: -1212.7
18
19  1 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
20  10 EQU: -12650: 0.0815: 0.19861: 22335.8: 6224.3: 0.459: -1120.1
21
22  2 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
23  10 EQU: -1003.9: -0.027: 0.1574: 2913: 1024: 0.59: 1258
24
25  3 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
26  10 EQU: -13654: 0.06617: 0.1927: 25249.4: 7248.6: .478: 137.7
27
28  4 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
29  10 EQU: -9473: 75.77: 37.935: 8817: 12.9: -90.755: -942.9
30
```

11 Table
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.6 and LV-calculation, arranged in 3 lines.
Line 1: LV-calculation, line 2: ASME, line 3: Difference in %.

	Conversion factors							
:	MPa2psi :	N2lb :	mm2in :					
1	145	0.2248	0.03937	0	0	0	0	
2	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0

---- Step 7+8+9 for calculation case 5(O1) ----------

:	Q2 :	Q3 :	Fm :	|Sig| :	|Tau| :	Ftmin :	Sigt1 :	MaxDiff%
4	-12633	0.08071	0.1977	22323		0.4536	-1143	
5	-12650	0.08101	0.1984	22367		0.46	-1112	
6	-0.1345	-0.3747	-0.3587	-0.1986		-1.387	2.826	2.826

---- Step 7+8+9 for calculation case 6 (O2) ----------

:	Q2 :	Q3 :	Fm :	|Sig| :	|Tau| :	Ftmin :	Sigt1	:MaxDiff%
7	-10457	0.911	0.5316	9980		-0.5591	301.1	
8	-10477	0.913	0.5333	9995		-0.543	314.9	
9	-0.192	-0.2234	-0.3183	-0.1409		2.966	-4.371	2.966

---- Step 7+8+9 for calculation case 7 (O3)----------

:	Q2 :	Q3 :	Fm :	|Sig| :	|Tau| :	Ftmin :	Sigt1(*):	MaxDiff%
10	-13636	0.0655	0.1919	25232		0.4722	110.2	
11	-13654	0.06578	0.1926	25281		0.478	146	
12	-0.1339	-0.4251	-0.365	-0.1928		-1.22	0	0.4251

--- Step 9+10+11, calculation case 1 (D1)----------

:	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSm :	
13	1.493	4075	-1152	2	5422	10.39	3.358	0
14	1.487	4047	1120	2	5336	10.4	3.4	
15	0.4002	0.6956	2.807	0	1.597	-0.0501	-1.226	2.807

--- Step 9+10+11, calculation case 2 (D2)----------

:	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSm :	
16	1.354	1888	1253	2	5422	-1525	-492.8	0
17	1.349	1887	0	0	5336	-1525	-492.7	
18	0.3348	0.03922	0	0	1.597	0.02085	0.02716	1.597

--- Step 9+10+11, calculation case 3 (D3)----------

:	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSm :	
19	1.473	5964	101.9	2	5422	-1518	-490.5	0
20	1.468	5933	0	0	5336	-1518	-490.5	
21	0.3557	0.5268	0	0	1.597	-0.01581	-0.01013	1.597

--- Step 9+10+11, calculation case 4 (O4)----------

:	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSm :	
22	98.84	1027	-952.3	1.25	8674	-28.18	-9.104	0
23	97.82	1016	942.9	1.25	8538	-28.2	-9.1	
24	1.042	1.05	0.9972	0	1.596	-0.07223	0.04605	1.596

--- Step 9+10+11, calculation case 5 (O1)----------

:	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSm :	
25	1.492	4089	-1143	2	5422	-21.47	-6.935	0
26	1.487	4061	1112	2	5336	-21.4	-6.9	
27	0.358	0.6949	2.826	0	1.597	0.3041	0.5053	2.826

--- Step 9+10+11, calculation case 6 (O2) ----------

:	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSm :	
28	2.563	2916	301.1	1.969	5508	-1557	-502.9	0
29	2.545	2902	0	0	5336	-1557	-503	
30	0.6943	0.4747	0	0	3.214	-0.01689	-0.0172	3.214

Links

1 1 UHXb: MPa2psi = 145: N2lb = 0.2248: mm2in=0.03937: : : :
2 11 EQU: : : : : : :
3
4 5 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
5 11 EQU: -12650: 0.08101: 0.1984: 22367.1: 6238.8: 0.460: -1111.8
6
7 6 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
8 11 EQU: -10477: 0.91305: 0.5333: 9994.5: 1037.2: -0.543: 314.9
9
10 7 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
11 11 EQU: -13654: 0.06578: 0.19264: 25280.7: 7263.2: 0.478: 146
12
13 1 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #320*MPa2psi:
14 11 EQU: 1.487: 4046.9: 1120.1: 2: 5336.3: 10.4: 3.4
15

16 2 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #320*MPa2psi:
17 11 EQU: 1.349: 1886.8: 0: 0: 5336.3: -1525.12: -492.7
18
19 3 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #320*MPa2psi:
20 11 EQU: 1.468: 5932.7: 0: 0: 5336.3: -1518.3: -490.5
21
22 4 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #320*MPa2psi:
23 11 EQU: 97.817: 1016.3: 942.9: 1.25: 8538.1: -28.2: -9.1
24
25 5 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #320*MPa2psi:
26 11 EQU: 1.487: 4061.2: 1111.8: 2: 5336.3: -21.4: -6.9
27
28 6 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #320*MPa2psi:
29 11 EQU: 2.545: 2902.1: 0: 0: 5336.3: -1556.9: -503
30

12 Table
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.6 and LV-calculation. Results arranged in
3 lines, line 1: LV calculation, line 2: ASME results, line 3: difference.

	:---Conversion factors----------							:Maximum
:	MPa2psi :	N2lb :	mm2in :					:Diff %
1	145	0.2248	0.03937	0	0	0	0	
2								
3	0	0	0	0	0	0	0	0
--- Step 11, SigSb for calculation case 1-7 ----------								
:	Case 1 :	2 :	3 :	4 :	5 :	6 :	7 :	
4	-41073	615.6	-40460	-20034	-41106	-19421	-40494	0
5	-41042	-618.6	-40167	-20025	-41070	-19151	-40195	
6	0.07561	-0.4892	0.7293	0.04444	0.08875	1.413	0.7423	1.413
--- Plastic calculation case 1 and 3, UHX-20.2.2(c)(12)----------								
:	case 1: case 3 : Tubesheet bending stress sigma ----------							
7	22369	25289						
8	23358	26304						
9	-4.236	-3.858	0	0	0	0	0	4.236

Links

1	1 UHXb: MPa2psi = 145: N2lb = 0.2248: mm2in=0.03937: : : :
2	
3	
4	1 UHXb: #143(1)*MPa2psi: #143(2)*MPa2psi: #143(3)*MPa2psi: #143(4)*MPa2psi: #143(5)*MPa2psi: #143(6)*MPa2psi: #143
5	12 EQU: -41041.6: -618.6: -40167.3: -20025: -41069.7: -19150.8: -40195.4
6	
7	9 UHXb: #138(8)*MPa2psi: #138(9)*MPa2psi
8	12 EQU: 23358: 26304

Appendix: Material documentation

Section 1: Boden/UHXb
Section 1: Mantel/UHXb
Section 1: Mantel-Zeitst/UHXb
Section 2: Boden/UHXb
Section 2: Mantel/UHXb
Section 2: Mantel-Zeitst/UHXb
Section 3: Boden/UHXb
Section 3: Mantel/UHXb
Section 3: Mantel-Zeitst/UHXb
Section 4: Boden/UHXb
Section 4: Mantel/UHXb
Section 4: Mantel-Zeitst/UHXb
Section 5: Boden/UHXb
Section 5: Mantel/UHXb
Section 5: Mantel-Zeitst/UHXb
Section 6: Boden/UHXb
Section 6: Mantel/UHXb
Section 6: Mantel-Zeitst/UHXb
Section 7: Boden/UHXb
Section 7: Mantel/UHXb
Section 7: Mantel-Zeitst/UHXb
Section 8: Boden/UHXb
Section 8: Mantel/UHXb
Section 8: Mantel-Zeitst/UHXb
Section 9: Boden/UHXb
Section 9: Mantel/UHXb
Section 9: Mantel-Zeitst/UHXb

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]: 357,2222 Pressure [bar]: 0
Thickness [mm]: 120,65 Outside diameter [mm]: 835,03

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	126,56
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	126,56
Modulus of elasticity [kN/mm²]:	202	177,8445

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 1: Rohre/UHXb
Section 1: Rohre-Zeitst/UHXb
Section 2: Rohre/UHXb
Section 2: Rohre-Zeitst/UHXb
Section 3: Rohre/UHXb
Section 3: Rohre-Zeitst/UHXb
Section 4: Rohre/UHXb
Section 4: Rohre-Zeitst/UHXb
Section 5: Rohre/UHXb
Section 5: Rohre-Zeitst/UHXb
Section 6: Rohre/UHXb
Section 6: Rohre-Zeitst/UHXb
Section 7: Rohre/UHXb
Section 7: Rohre-Zeitst/UHXb
Section 8: Rohre/UHXb
Section 8: Rohre-Zeitst/UHXb
Section 9: Rohre/UHXb
Section 9: Rohre-Zeitst/UHXb

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-214 Product: Wld. tube
Material code: K01807-SA-214--Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 343,33 Pressure [bar]: 0
Thickness [mm]: 2,11 Outside diameter [mm]: 19,05

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	78,60	75,34
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	78,60	75,34
Modulus of elasticity [kN/mm²]:	202	179,8004

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
	78.6	78.6	78.6	78.6	78.1	74.7	62.3	

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
	47.6	27.1	10.6				

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 1: Boden-Zeitst/UHXb
Section 1: Schale-1-Bodenbereich/UHXb
Section 2: Boden-Zeitst/UHXb
Section 2: Schale-1-Bodenbereich/UHXb
Section 3: Boden-Zeitst/UHXb
Section 3: Schale-1-Bodenbereich/UHXb
Section 4: Boden-Zeitst/UHXb
Section 4: Schale-1-Bodenbereich/UHXb
Section 5: Boden-Zeitst/UHXb
Section 5: Schale-1-Bodenbereich/UHXb
Section 6: Boden-Zeitst/UHXb
Section 6: Schale-1-Bodenbereich/UHXb
Section 7: Boden-Zeitst/UHXb
Section 7: Schale-1-Bodenbereich/UHXb
Section 8: Boden-Zeitst/UHXb
Section 8: Schale-1-Bodenbereich/UHXb
Section 9: Boden-Zeitst/UHXb
Section 9: Schale-1-Bodenbereich/UHXb

Material specification:

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

Design conditions and dimensions:

Temperature [°C]:	357,22	Pressure [bar]:	0
Thickness [mm]:	120,65	Outside diameter [mm]:	835,03

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	126,56
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	126,56
Modulus of elasticity [kN/mm²]:	202	177,8448

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 1: mittlere W-dehn. Mantel/UHXb
Section 1: mittl. W-dehn. Schale-1/UHXb
Section 2: mittlere W-dehn. Mantel/UHXb
Section 2: mittl. W-dehn. Schale-1/UHXb
Section 3: mittlere W-dehn. Mantel/UHXb
Section 3: mittl. W-dehn. Schale-1/UHXb
Section 4: mittlere W-dehn. Mantel/UHXb
Section 4: mittl. W-dehn. Schale-1/UHXb
Section 5: mittlere W-dehn. Mantel/UHXb
Section 5: mittl. W-dehn. Schale-1/UHXb
Section 6: mittlere W-dehn. Mantel/UHXb
Section 6: mittl. W-dehn. Schale-1/UHXb
Section 7: mittlere W-dehn. Mantel/UHXb
Section 7: mittl. W-dehn. Schale-1/UHXb
Section 8: mittlere W-dehn. Mantel/UHXb
Section 8: mittl. W-dehn. Schale-1/UHXb
Section 9: mittlere W-dehn. Mantel/UHXb
Section 9: mittl. W-dehn. Schale-1/UHXb

Material specification:

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

Design conditions and dimensions:

Temperature [°C]:	287,78	Pressure [bar]:	0
Thickness [mm]:	12,7	Outside diameter [mm]:	609,6

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	136,49
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	136,49
Modulus of elasticity [kN/mm²]:	202	185,9776

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 1: mittlere W-dehn. Rohre/UHXb
Section 2: mittlere W-dehn. Rohre/UHXb
Section 3: mittlere W-dehn. Rohre/UHXb
Section 4: mittlere W-dehn. Rohre/UHXb
Section 5: mittlere W-dehn. Rohre/UHXb
Section 6: mittlere W-dehn. Rohre/UHXb
Section 7: mittlere W-dehn. Rohre/UHXb
Section 8: mittlere W-dehn. Rohre/UHXb
Section 9: mittlere W-dehn. Rohre/UHXb

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-214 Product: Wld. tube
Material code: K01807-SA-214--Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 254,44 Pressure [bar]: 0
Thickness [mm]: 2,11 Outside diameter [mm]: 19,05

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	78,60	78,56
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	78,60	78,56
Modulus of elasticity [kN/mm²]:	202	188,6448

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
	78.6	78.6	78.6	78.6	78.1	74.7	62.3	

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
	47.6	27.1	10.6				

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 1: Schale-1 Zeitst/UHXb
Section 2: Schale-1 Zeitst/UHXb
Section 3: Schale-1 Zeitst/UHXb
Section 4: Schale-1 Zeitst/UHXb
Section 5: Schale-1 Zeitst/UHXb
Section 6: Schale-1 Zeitst/UHXb
Section 7: Schale-1 Zeitst/UHXb
Section 8: Schale-1 Zeitst/UHXb
Section 9: Schale-1 Zeitst/UHXb

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]: 287,7778 Pressure [bar]: 0
Thickness [mm]: 31,75 Outside diameter [mm]: 609,6

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	136,49
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	136,49
Modulus of elasticity [kN/mm²]:	202	185,9778

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 1: Bodenrand-3/UHXb
Section 1: Schale-Rand-3/UHXb
Section 1: Schale-Rand-3 UHX-13.6□ع
Section 2: Bodenrand-3/UHXb
Section 2: Schale-Rand-3/UHXb
Section 2: Schale-Rand-3 UHX-13.6□ع
Section 3: Bodenrand-3/UHXb
Section 3: Schale-Rand-3/UHXb
Section 3: Schale-Rand-3 UHX-13.6□ع
Section 4: Bodenrand-3/UHXb
Section 4: Schale-Rand-3/UHXb
Section 4: Schale-Rand-3 UHX-13.6□ع
Section 5: Bodenrand-3/UHXb
Section 5: Schale-Rand-3/UHXb
Section 5: Schale-Rand-3 UHX-13.6□ع
Section 6: Bodenrand-3/UHXb
Section 6: Schale-Rand-3/UHXb
Section 6: Schale-Rand-3 UHX-13.6□ع
Section 7: Bodenrand-3/UHXb
Section 7: Schale-Rand-3/UHXb
Section 7: Schale-Rand-3 UHX-13.6□ع
Section 8: Bodenrand-3/UHXb
Section 8: Schale-Rand-3/UHXb
Section 8: Schale-Rand-3 UHX-13.6□ع
Section 9: Bodenrand-3/UHXb
Section 9: Schale-Rand-3/UHXb
Section 9: Schale-Rand-3 UHX-13.6□ع

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]: 20 Pressure [bar]: 0
Thickness [mm]: 120,65 Outside diameter [mm]: 835,03

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	202

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 1: Bolts/Schrauben/UHXb
Section 2: Bolts/Schrauben/UHXb
Section 3: Bolts/Schrauben/UHXb
Section 4: Bolts/Schrauben/UHXb
Section 5: Bolts/Schrauben/UHXb
Section 6: Bolts/Schrauben/UHXb
Section 7: Bolts/Schrauben/UHXb
Section 8: Bolts/Schrauben/UHXb
Section 9: Bolts/Schrauben/UHXb

Material specification:

Regulation: ASMET3:2010Spec. No.: SA-193 Product: Bolting
Material code: G41400-SA-193-B7-Class:-Size:<=64 Short name: 1Cr-0.2Mo

Design conditions and dimensions:

Temperature [°C]: 357,22 Pressure [bar]: 0
Thickness [mm]: 30,81 Outside diameter [mm]: 30,81

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	172,00	172,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	172,00	172,00
Modulus of elasticity [kN/mm²]:	204	182,4224

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
		172	172	172	172	172	172	162

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
	118	68.8	18.9				

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
150	210	218	213	204	200	197	193	190	186	183	179	174	169	164

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

600	700			
157	142			

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 1: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 2: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 3: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 4: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 5: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 6: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 7: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 8: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 9: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-214 Product: Wld. tube
Material code: K01807-SA-214--Class:-Size: Short name: Carbon steel

Design conditions and dimensions:

Temperature [°C]: 357,2222 Pressure [bar]: 0
Thickness [mm]: 2,11 Outside diameter [mm]: 19,05

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	78,60	73,75
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	78,60	73,75
Modulus of elasticity [kN/mm²]:	202	177,8445

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
	78.6	78.6	78.6	78.6	78.1	74.7	62.3	

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
	47.6	27.1	10.6				

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					