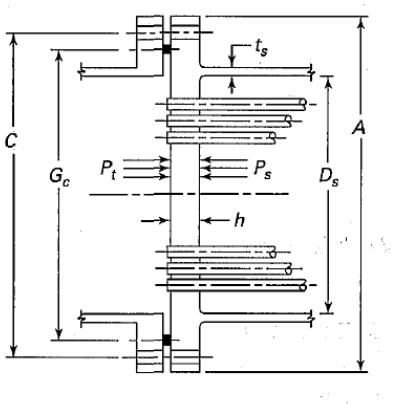
Table of contents

Example E4.18.5 - Fixed Tubesheet Exchanger, Configuration b, Tubesheet Integral with Shell, Extended as a Flange and Gasketed on the Channel Side

A fixed tubesheet hegt exchanger is to be designed with the tubesheet construction in accordance with configuration b as shown in VIII-1, Figure UHX-13.1, Configuration b.



(b) Configuration b: Tubesheet Integral With Shell and Gasketed With Channel, Extended as a Flange

- For the Design Condition, the shell side design pressure is 150 psig at 700°F, and the tube side design pressure is 400 psig at 700°F.
- There is one operating condition. For Operating Condition 1, the shell side design pressure is 150 psig at 700°F, the tube side design pressure is 400 psig at 700°F, the shell mean metal temperature is 550°F, and the tube mean metal temperature is 510°F. For this example, the operating pressures and operating metal temperatures are assumed to be the same as the design values.
- The tube material is SA-214 welded (K01807). The tubes are 1 in. outside diameter, 0.083 in. thick and are to be expanded to 95% of the tubesheet thickness.
- The tubesheet material is SA-516, Grade 70 (K02700). The tubesheet outside diameter is 40.5 in. There are 649 tube holes on a 1.25 in. triangular pattern. There is no pass partition lane, and the outermost tube radius from the tubesheet center is 16.625 in. The distance between the outer tubesheet faces is 168 in. There is no corrosion allowance on the tubesheet.
- The shell material is SA-516, Grade 70 (K02700). The shell inside diameter is 34.75 in. and the thickness is 0.1875 in. There is no corrosion allowance on the shell. The shell contains an expansion joint that has an inside diameter of 38.5 in. and an axial rigidity of 11.388 lb/in. The efficiency of the shell circumferential welded joint (Category B) is 1.0.
- The diameter of the channel flange gasket load reaction is 36.8125 in., the bolt circle diameter is 38.875 in., the design bolt load is 512,937 lb, and the operating condition bolt load is 512,473 lb.

Data Summary - Tubesheet

Tube Layout: Triangular

h	= 3.0625 in.
h_g	= 0 in.
c_t	= 0 in.
A	= 40.5in.
r_0	= 16.625in.
A_L	= 0.0in.^{2}
N_t	= 649
L_t	= 168in.
p	= 1.2500 in.
T	= 700°F
T_a	= 70°F
S	= 18,100 psi at T from Table 1A of Section II, Part D
Sy	= 27,200 psi at T
S_{PS}	= 54,400 psi at T
E	= 25.5E6 psi at T from TM-1 of Section II, Part D
v	= 0.3

Data Summary - Tubes

$P_{td,max}$	= 400 psig
$P_{td,min}$	= 0 psig
P_{so1}	= 400 psig
ℓ_{tx}	= 2.909in.
k	= 1
ℓ	= 59in.
t_t	= 0.083 in.
d_t	= 1 in.
T_t	= 700°F
$T_{t,m}$	= 510°F
S_t	=10,500 psi at T_t from Table 1A of Section II, Part D
$S_{y,t}$	=18,600 psiat T_t from Y-1 of Section II, Part D
S_{tT}	=10,500 psiat T from Table lA of Section II, Part D
A	= 7.3E-06 in. / in.° F at $T_{t,m}$
E_t	= 25,500,000 psi at T_t from TM-1 of Section II, Part D
E_{tT}	= 25,500,000 psi at T from TM-1 of Section II, Part D
v	= 0.3

Note: Since the tubes are welded (SA-214), the tube allowable stresses St and Str can be divided by 0.85 per VIII-1, paragraph UHX-13.3. This results in adjusted values of S_t =12,353 psi and S_{tT} =12,353 psi.

Data Summary - Shell

$P_{sd,max}$ = 150 psig
$P_{sd,min}$ = 0 psig
P_{so1} = 150 psig
t_s = 0.1875 in.
D_s = 34.75 in.
D_j = 38.5in.
K_j = 11,388 lb/in.
T_s = 700°F
$T_{s,m}$ = 550°F
S_s = 18,100 psi at Ts from Table 1A of Section II, Part D
$E_{s,w}$ = 1.0
$S_{y,s}$ = 27,200 psi from Table Y-1 of Section II, Part D
$S_{PS,s}$ = 54,400 psi at T see UG-23(e)
E_s = 25,500,000 psi from TM-1 of Section 11, Part D
$a_{s,m}$ = 7.3E-06 in./in./°F at $T_{s,m}$
v_s = 0.3

Data Summary - Channel Flange

Gasket I.D. = 36.3125 in.
Gasket O.D. = 37.3125 in.
Mean Gasket Diameter, G =G_c = 36.8125in.
Gasket,m,Factor = 3.75
Gasket,y, Factor = 7,600 psi
Flange Outside Diameter = 40.5 in.
Bolt Circle,C = 38.875 in.
Bolting Data = 68 bolts, 0.75 in.diameter
BoltingMaterial = SA-193 B7
Boll Load,W = 512,937 lb per VIII-1 Appendix 2
Bolt Load,W_{m1} = 512,473 lb per VIII-1 Appendix 2
W*from Table UHX-8.1
Gasket Moment Arm, hg = (C - G_c)/2 =1.03125 in.

1 E4.18.5.D1
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

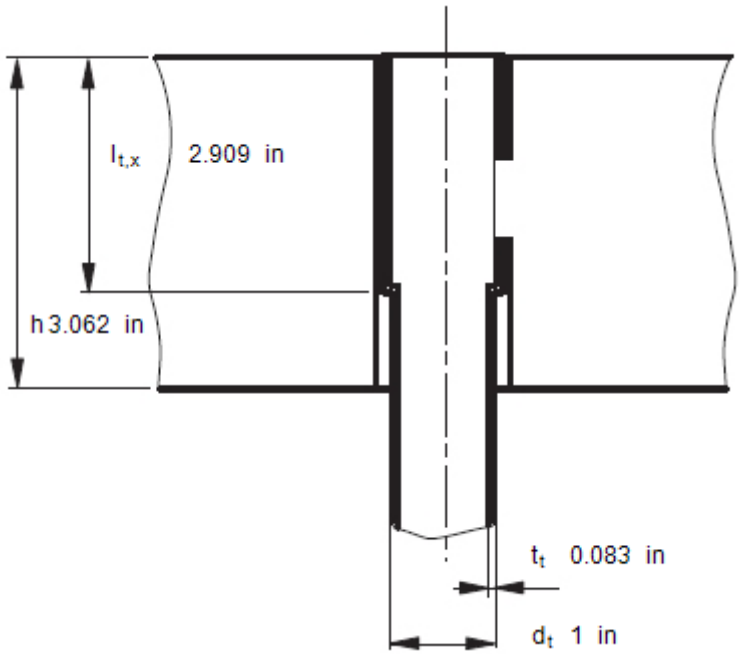
Configuration of the tubesheet (a, b, c, d)	Type	*b*	(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	(1,2)
Internal operation pressure shell side	P_s	*150*	psi
Internal operation pressure tube side	P_t	*400*	psi
Internal 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		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	***35.13***	in
Poisson's ratio	-			*0.3*		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
Young's modulus		*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion		*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength		*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		***17952***	psi	**10430**	psi	***17952***	psi
Prim.+sec. str.		***54515***	psi			***54515***	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

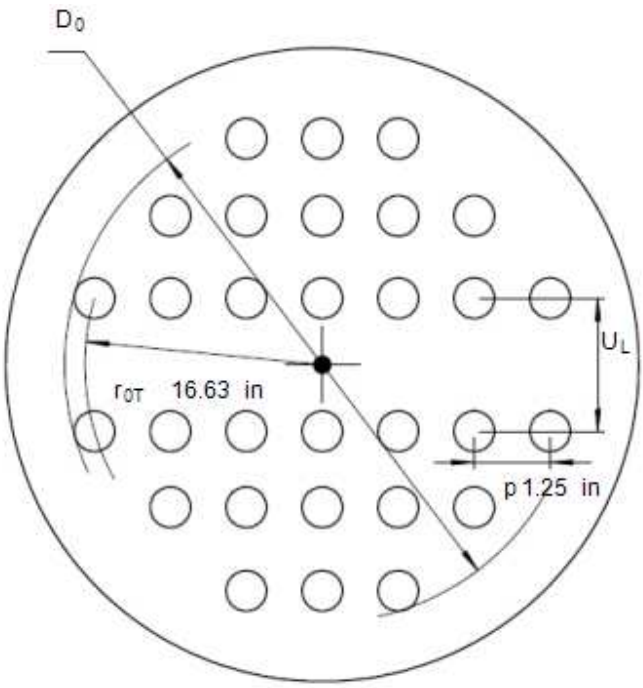
Additional specifications for the geometry and loading

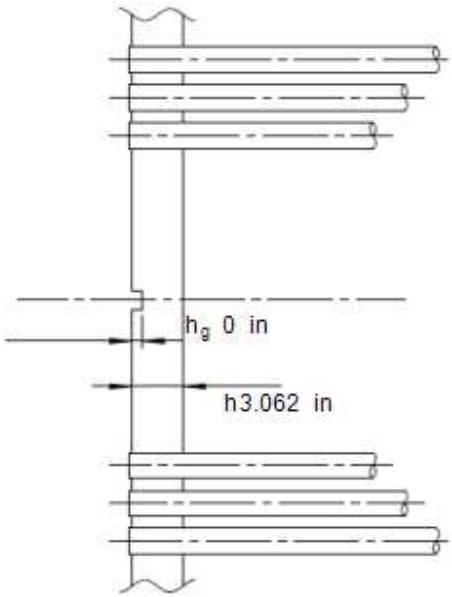
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*649*	



Expanded length of tube in tubesheet		$l_{t,x}$	***2.909***	in
Expanded length ratio $l_{t,x}$/h		ρ	0.95	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*16.63*	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	*1.25*	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	*161.9*	in
Unsupported tube span for buckling	l	59	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	***59***	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	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}	*510*	°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}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	-
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	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	*37.31*	in
Contact inside diameter	G_i		in	36.31	in
Basic seating width	b_0		in	*0.255*	in
Gasket factor (Table 2-5.1)	m			*3.75*	
Gasket seating pressure	Y		psi	*7600*	psi
Diameter of gasket force	G		in	***36.81***	in
Poisson's ratio	v	0.3		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512365**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.234**	in

Maximum bolt force for all calculation cases	W_{max}	*512937*	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	**512806**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	34.75	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T				E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T				K_{tT}	12000	psi
Tube material allowable stress safety at T				S_{fT}	1	-
Basic ligament efficiency for shear				μ	**0.2**	
Effective tube hole diameter				d*	**0.8946**	in
Effective pitch				p*	**1.25**	in
Effective ligament efficiency for shear				μ*	**0.2843**	
Effective depth of pass partition groove				h_g'	**0**	in
Equivalent radius of outer tube limit circle				a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)				a_c	**18.41**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)				a_s	**17.38**	in
Ratio = ac/a0				ρ_C	**1.075**	
Ratio = as/a0				ρ_S	**1.015**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$				x_s	**0.4467**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$				x_t	**0.6152**	
Type abc: Coefficients for shell pressure				δ_S	**0.1979**	mm^3/N
β_S	**8.523** 1/ft	k_S	**21842** lbf	λ_S	**878462**	psi

Step 2

Shell axial rigidity K_s or K_s*			K_s	**3238266**	lbf/in
Tube axial rigidity			K_t	**37624**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$			K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)			J	**0.003504**	

Step 3

Effective modulus of el. tubesheet	UHX-11.3				E*	**6640239**	psi
Ratio of elasticity tubesheet					E*/E	**0.2607**	
effective Poisson's ratio tubesheet					v*	**0.3653**	
Parameter for table UHX-13.1					X_a	**3.971**	
Z_d **0.02446**	Z_v **0.06398**	Z_m **0.3705**	Z_a **6.611**		Z_w	**0.06398**	

Step 4

Diameter ratio = A/D0						K	**1.182**
F	**0.492**	Φ	**0.6718**			Q_1	**-0.02273**
Q_{z1}	**2.859**	Q_{z2}	**6.905**			U	**13.81**

UHX-13.5.5 Step 5, coefficients

γ(*)	**0** in	ω_S	**2.685**	in²		ω_S*	**-2.654** in²
ω_C	**0** in²	ω_C*	**9.677**	in²		γ_b	**-0.06025**

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'	**861033**	psi		P_γ	**0** psi
P_W	**231.6** psi	P_{rim}	**182.3**	psi		P_e	**-399.4** psi

UHX-13.5.7 Step 7

Q_2	**-7038** lbf	Q_3	**0.09743**			F_m	**0.09737**

Strength condition for the tubesheet bending stress, case 1

σ =	**25662** psi	< 1.5 · σ_B	= 1.5·	***17952***	psi	case 1-3	
		< S_{PS}	=	***54515***	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14362** 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}	-1.081		F_{tmax}	3.815	
x_{min}	0		x_{max}	3.971	
$\sigma_{T,1}$	-4025	psi	$\sigma_{T,2}$	7585	psi

σ_{tmax} = 7585 psi ≤ σ_T = 10430 psi for calculation case 1-3
≤2 · σ_T = 20860 psi for calculation case 4-7

Tube weld force W_t = 1814 lbf ≤ $W_{t,all}$ = 0 lbf
(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t 0.3255 in F_t 181.2 C_t 1.343 F_s 164.2

$|\sigma_{tmin}|$ = | -4025 psi | ≤S_{tb} = 5700 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 = *0.1875* in : (calculation case)
σ_{Sm} ≤ *1*· ***17952*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)
σ_{Sm} = 26.16 psi ≤2· ***17952*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: | σ_{Sm} | < Min(B, A·E/2) acc. UG-23(b)
| 26.16 psi | < Min(8493 psi , 16996 psi)
ASME external pressure chart CS-2 A = 0.001335

Region of increased thickness t_{1s} = in : (calculation case)
σ_{Sm} ≤ *1*· psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)
σ_{Sm} = psi ≤2· psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: | σ_{Sm} | < Min(B, A·E/2) acc. UG-23(b)
| psi | < Min(psi , psi)
ASME external pressure chart A =

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 = | σ_{Sm} | + | σ_{Sb} | = 42611 psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}
σ_S = | 26.16 psi | + | -42585 psi | ≤ 26929 psi
σ_C = | σ_{Cm} | + | σ_{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} 4.595 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	**2.547e+7** psi	**2.547e+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 = **42611** psi ≤ ***54515*** 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= *3.062* in < *1* 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
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.79\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 77.79\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.3\ \text{mm} + 25.4\ \text{mm}) = 870\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(31.75\ \text{mm} - 25.4\ \text{mm})}{31.75\ \text{mm}} = 0.2$$

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567122\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6589\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.9\ \text{mm}}{77.79\ \text{mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (870\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{MPa}}{175622\ \text{MPa}} \cdot \frac{71.91\ \text{MPa}}{123.8\ \text{MPa}} \cdot 0.95\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 22.72\ \text{mm}}{22.72\ \text{mm}} = 0.2843$$

2 E4.18.5.D2
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

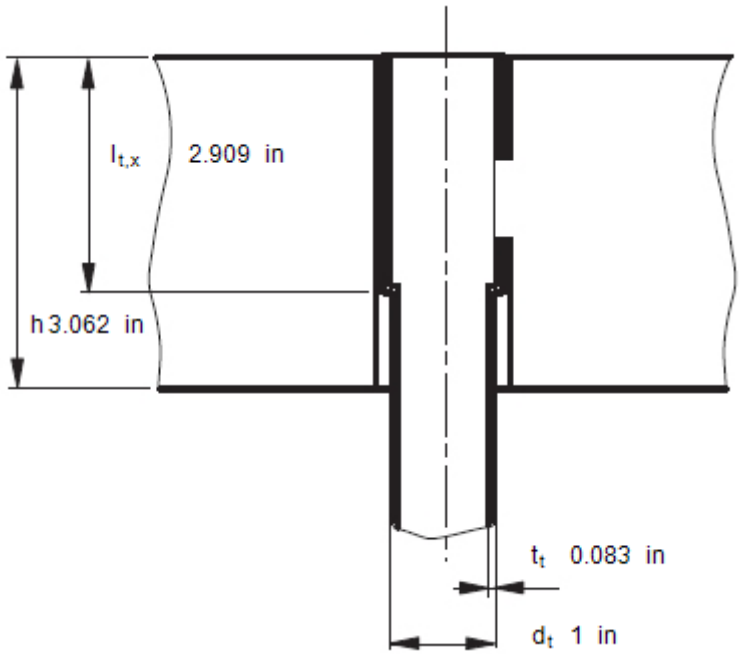
Configuration of the tubesheet (a, b, c, d)	Type	b	(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operation pressure shell side	P_s	150	psi
Internal operation pressure tube side	P_t	400	psi
Internal test pressure 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		700	°F	700	°F	700	°F
Thickness		3.062	in	0.083	in	0.1875	in
Outside diameter		40.5	in	1	in	35.13	in
Poisson's ratio		-		0.3		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	0	in	0	in	0	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
Young's modulus		2.547e+7	psi	2.547e+7	psi	2.547e+7	psi
Thermal expansion		7.586	1E-6/°F	7.586	1E-6/°F	7.586	1E-6/°F
Yield strength		27257	psi	18655	psi	27257	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		17952	psi	12353	psi	**17952**	psi
Prim.+sec. str.		54515	psi			**54515**	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

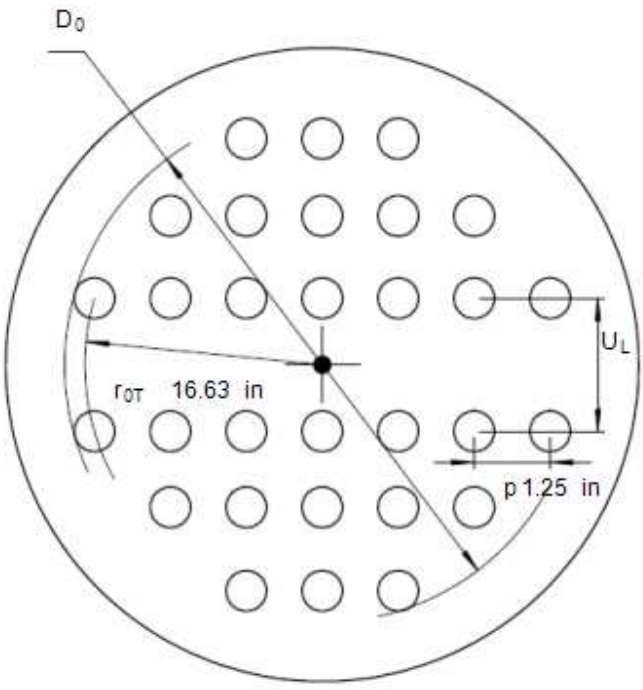
Additional specifications for the geometry and loading

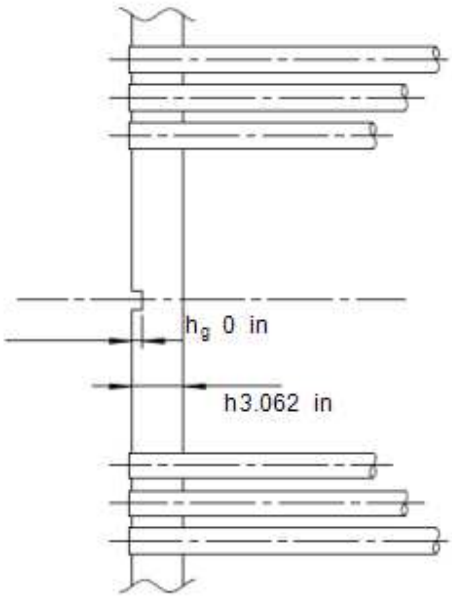
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		1	(1, 2)
Number of tubes		N_t	649	



Expanded length of tube in tubesheet		$l_{t,x}$	2.909	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.95**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63	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	1.25	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	161.9	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	59	in
Bellows inside diameter at its convolution height	D_j	38.5	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	11388	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}	510	°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}	7.3	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	38.88	in
Number of bolts	n	68	-
Bolt root diameter	d_B	0.62	in
Total bolt area	A_b	**20.53**	in²
Bolt material G41400-SA-193-B7-Class:-Size:<=64			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	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	37.31	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	0.255	in
Gasket factor (Table 2-5.1)	m			3.75	
Gasket seating pressure	Y		psi	7600	psi
Diameter of gasket force	G		in	**36.81**	in
Poisson's ratio	v	0.3		0.3	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**8.802**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**0.9877**	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	**366650**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T				E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T				K_{tT}	12000	psi
Tube material allowable stress safety at T				S_{fT}	1	-
Basic ligament efficiency for shear				μ	**0.2**	
Effective tube hole diameter				d*	**0.8946**	in
Effective pitch				p*	**1.25**	in
Effective ligament efficiency for shear				μ*	**0.2843**	
Effective depth of pass partition groove				h_g'	**0**	in
Equivalent radius of outer tube limit circle				a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)				a_c	**18.41**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)				a_s	**17.37**	in
Ratio = ac/a0				ρ_C	**1.075**	
Ratio = as/a0				ρ_S	**1.015**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$				x_s	**0.4467**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$				x_t	**0.6152**	
Type abc: Coefficients for shell pressure				δ_S	**0.1979**	mm^3/N
β_S	**8.523** 1/ft	k_S	**21842** lbf	λ_S	**878462**	psi

Step 2

Shell axial rigidity K_s or K_s*			K_s	**3238266**	lbf/in
Tube axial rigidity			K_t	**37624**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$			K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)			J	**0.003504**	

Step 3

Effective modulus of el. tubesheet	UHX-11.3				E*	**6640243**	psi
Ratio of elasticity tubesheet					E*/E	**0.2607**	
effective Poisson's ratio tubesheet					v*	**0.3653**	
Parameter for table UHX-13.1					X_a	**3.971**	
Z_d **0.02446**	Z_v **0.06398**	Z_m **0.3705**	Z_a **6.611**		Z_w	**0.06398**	

Step 4

Diameter ratio = A/D0						K	**1.182**
F	**0.492**	Φ	**0.6718**			Q_1	**-0.02273**
Q_{z1}	**2.859**	Q_{z2}	**6.905**			U	**13.81**

UHX-13.5.5 Step 5, coefficients

γ(*)	**0** in	ω_S	**2.685**	in²	ω_S*	**-2.654**	in²
ω_C	**0** in²	ω_C*	**9.677**	in²	γ_b	**-0.06025**	

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'	**-46334** psi	P_t'	**0**	psi	P_γ	**0**	psi
P_W	**165.6** psi	P_{rim}	**18.74**	psi	P_e	**-21.42**	psi

UHX-13.5.7 Step 7

Q_2	**-318.7** lbf	Q_3	**0.07875**			F_m	**0.09004**

Strength condition for the tubesheet bending stress, case 2

σ =	**1273** psi	< 1.5 · σ_B	= 1.5·	17952	psi	case 1-3	
		< S_{PS}	=	54515	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau =	**0** psi	< 0.8· σ_B	=	**14362**	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}	-1.012		F_{tmax}	3.666	
x_{min}	0		x_{max}	3.971	
$\sigma_{T,1}$	269.1	psi	$\sigma_{T,2}$	864.1	psi

σ_{tmax} = 864.1 psi $\leq \sigma_T$ = 12353 psi for calculation case 1-3
$\leq 2 \cdot \sigma_T$ = 24706 psi for calculation case 4-7

Tube weld force W_t = 206.6 lbf $\leq W_{t,all}$ = 0 lbf
(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t 0.3255 in F_t 181.2 C_t 1.417 F_s 164.2

$|\sigma_{tmin}|$ = 269.1 psi $\leq S_{tb}$ = 5402 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 = 0.1875 in : (calculation case)
$\sigma_{Sm} \leq$ 1· 17952 psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)
σ_{Sm} = -761.4 psi ≤2· 17952 psi = $2 \cdot \sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)
|-761.4 psi| < Min(8493 psi , 16996 psi)
ASME external pressure chart CS-2 A = 0.001335

Region of increased thickness t_{1s} = in : (calculation case)
$\sigma_{Sm} \leq$ 1· psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)
σ_{Sm} = psi ≤2· psi = $2 \cdot \sigma_{allS}$ (4-7)

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

Strength condition 13.5.10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = 19973 psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}
σ_S = |-761.4 psi| + |19212 psi| ≤ 26929 psi
$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = 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} 4.595 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	**2.547e+7** psi	**2.547e+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 = **19973** psi ≤ **54515** 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= 3.062 in < 1 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
54515 psi = 3· **17952** psi or 2· 27257 psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.79\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 77.79\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.3\ \text{mm} + 25.4\ \text{mm}) = 870\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(31.75\ \text{mm} - 25.4\ \text{mm})}{31.75\ \text{mm}} = 0.2$$

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567122\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6589\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.9\ \text{mm}}{77.79\ \text{mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (870\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{MPa}}{175622\ \text{MPa}} \cdot \frac{85.17\ \text{MPa}}{123.8\ \text{MPa}} \cdot 0.95\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 22.72\ \text{mm}}{22.72\ \text{mm}} = 0.2843$$

3 E4.18.5.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	*150*	psi
Internal operation pressure tube side		P_t	*400*	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		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0*	in	*0*	in	*0*	in

Properties for the selected load case temperature

Strength operat.	17952	psi	10430	psi	17952	psi
Safety operation	1		1		1	
Young's modulus	*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion	*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength	*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature	752	°F	752	°F	752	°F
Allow. stress	*17952*	psi	12353	psi	***17952***	psi
Prim.+sec. str.	*54515*	psi			***54515***	psi

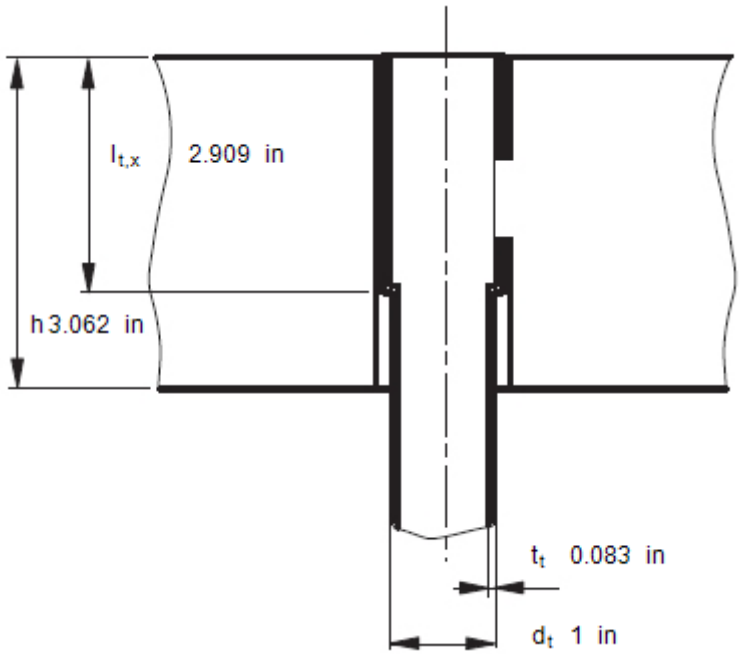
Properties for testing at 20°C

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

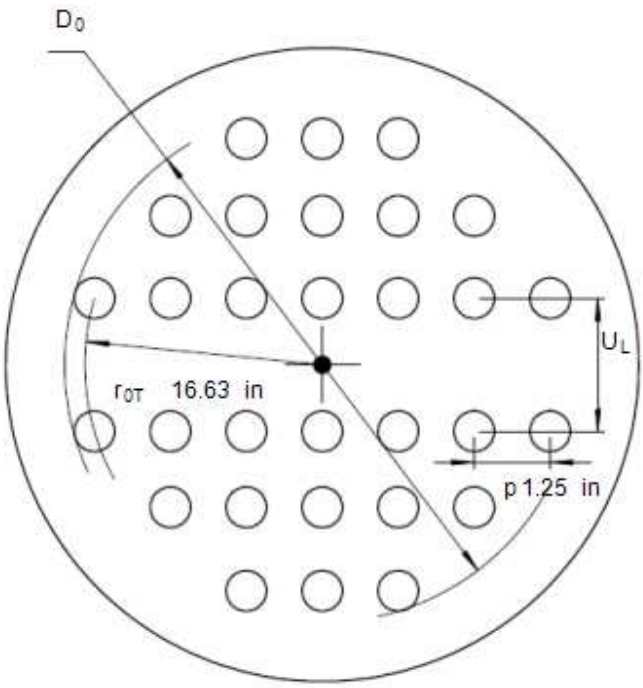
Additional specifications for the geometry and loading

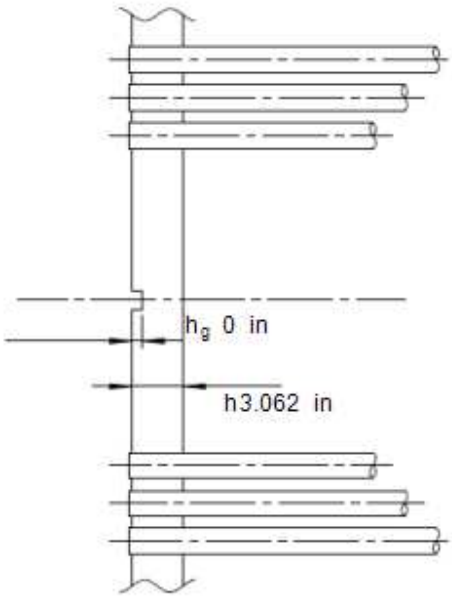
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*649*	



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.95**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*16.63*	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	*1.25*	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	*161.9*	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	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	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}	*510*	°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}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	-
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	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	*37.31*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.255*	in
Gasket factor (Table 2-5.1)	m			*3.75*	
Gasket seating pressure	Y		psi	*7600*	psi
Diameter of gasket force	G		in	***36.81***	in
Poisson's ratio	v	0.3		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512365**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.234**	in

Maximum bolt force for all calculation cases	W_{max}	*512937*	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	**512806**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T					E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T					K_{tT}	12000	psi
Tube material allowable stress safety at T					S_{fT}	1	-
Basic ligament efficiency for shear					μ	**0.2**	
Effective tube hole diameter					d*	**0.8946**	in
Effective pitch					p*	**1.25**	in
Effective ligament efficiency for shear					μ*	**0.2843**	
Effective depth of pass partition groove					h_g'	**0**	in
Equivalent radius of outer tube limit circle					a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)					a_c	**18.41**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)					a_s	**17.37**	in
Ratio = ac/a0					ρ_C	**1.075**	
Ratio = as/a0					ρ_S	**1.015**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$					x_s	**0.4467**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$					x_t	**0.6152**	
Type abc: Coefficients for shell pressure					δ_S	**0.1979**	mm^3/N
β_S	**8.523**	1/ft	k_S	**21842** lbf	λ_S	**878462**	psi

Step 2

Shell axial rigidity K_s or K_s*					K_s	**3238266**	lbf/in
Tube axial rigidity					K_t	**37624**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$					K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)					J	**0.003504**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3			E*	**6640243**	psi
Ratio of elasticity tubesheet					E*/E	**0.2607**	
effective Poisson's ratio tubesheet					v*	**0.3653**	
Parameter for table UHX-13.1					X_a	**3.971**	
Z_d	**0.02446**	Z_v	**0.06398**	Z_m **0.3705** Z_a **6.611**	Z_w	**0.06398**	

Step 4

Diameter ratio = A/D0					K	**1.182**	
F	**0.492**	Φ	**0.6718**		Q_1	**-0.02273**	
Q_{z1}	**2.859**	Q_{z2}	**6.905**		U	**13.81**	

UHX-13.5.5 Step 5, coefficients

γ(*)	**0**	in	ω_S	**2.685**	in²	ω_S*	**-2.654** in²
ω_C	**0**	in²	ω_C*	**9.677**	in²	γ_b	**-0.06025**

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'	**-46334**	psi	P_t'	**861033**	psi	P_γ	**0**	psi
P_W	**231.6**	psi	P_{rim}	**201**	psi	P_e	**-420.9**	psi

UHX-13.5.7 Step 7

Q_2	**-7356**	lbf	Q_3	**0.09646**		F_m	**0.09699**

Strength condition for the tubesheet bending stress, case 3

σ =	**26936**	psi	< 1.5 · σ_B	= 1.5·	*17952*	psi	case 1-3	
			< S_{PS}	=	*54515*	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = **0** psi < 0.8· σ_B = **14362** psi

UHX-13.5.7 Schritt 7: Bending stress Sig > 1.5*SigZul, tubesheet too thin

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

F_{tmin}	**-1.078**		F_{tmax}	**3.807**	
x_{min}	**0**		x_{max}	**3.971**	
$\sigma_{T,1}$	**-3756**	psi	$\sigma_{T,2}$	**8451**	psi

σ_{tmax} = **8451** psi ≤ σ_T = 12353 psi for calculation case 1-3
≤2 · σ_T = **24706** psi for calculation case 4-7

Tube weld force W_t = **2021** lbf ≤ $W_{t,all}$ = 0 lbf
(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t **0.3255** in F_t **181.2** C_t **1.346** F_s **164.2**

$|\sigma_{tmin}|$ = | **-3756** psi | ≤S_{tb} = **5684** 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 = *0.1875* in : (calculation case)
σ_{Sm} ≤ *1*· ***17952*** psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)
σ_{Sm} = **-738.6** psi ≤2· ***17952*** psi = $2\cdot\sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)
| **-738.6** psi | < Min(**8493** psi , **16996** psi)
ASME external pressure chart CS-2 A = **0.001335**

Region of increased thickness t_{1s} = in : (calculation case)
σ_{Sm} ≤ *1*· psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)
σ_{Sm} = psi ≤2· psi = $2\cdot\sigma_{allS}$ (4-7)

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

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 = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **24117** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}
σ_S = | **-738.6** psi | + | **-23378** psi | ≤ **26929** 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} **4.595** 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	**2.547e+7** psi	**2.547e+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 = **24117** psi ≤ ***54515*** 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= *3.062* in < *1* 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
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.79\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 77.79\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.3\ \text{mm} + 25.4\ \text{mm}) = 870\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(31.75\ \text{mm} - 25.4\ \text{mm})}{31.75\ \text{mm}} = 0.2$$

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567122\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6589\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.9\ \text{mm}}{77.79\ \text{mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (870\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{MPa}}{175622\ \text{MPa}} \cdot \frac{85.17\ \text{MPa}}{123.8\ \text{MPa}} \cdot 0.95\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 22.72\ \text{mm}}{22.72\ \text{mm}} = 0.2843$$

4 E4.18.5.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	*150*	psi
Internal operation pressure tube side	P_t	*400*	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		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0*	in	*0*	in	*0*	in

Properties for the selected load case temperature

Strength operat.	17952	psi	10430	psi	17952	psi
Safety operation	1		1		1	
Young's modulus	*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion	*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength	*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature	752	°F	752	°F	752	°F
Allow. stress	*17952*	psi	12353	psi	***17952***	psi
Prim.+sec. str.	*54515*	psi			***54515***	psi

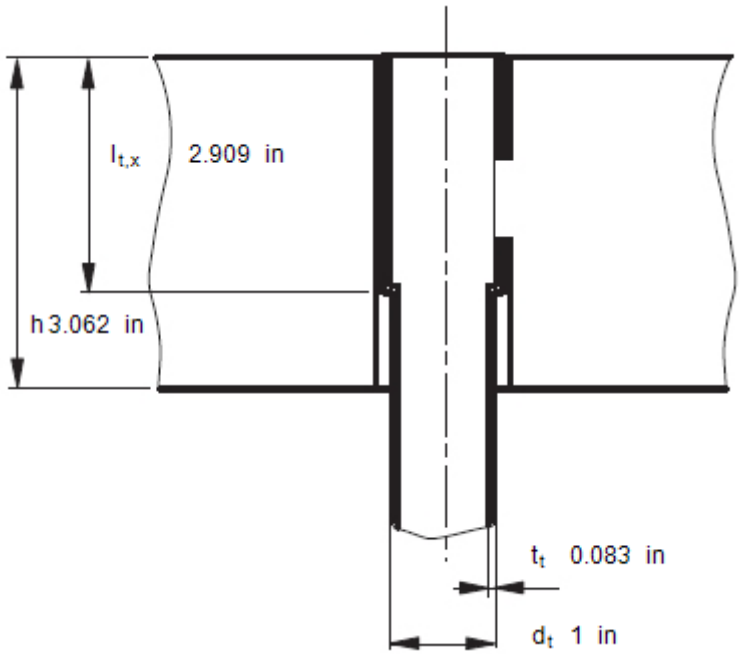
Properties for testing at 20°C

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

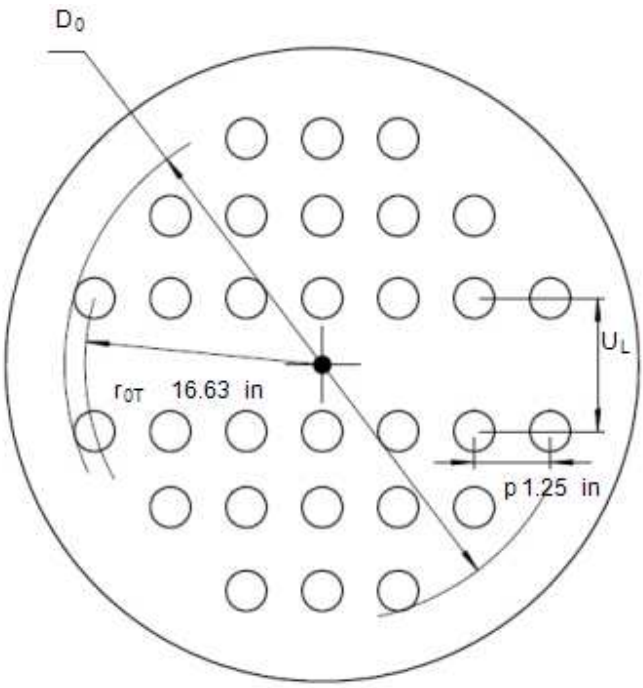
Additional specifications for the geometry and loading

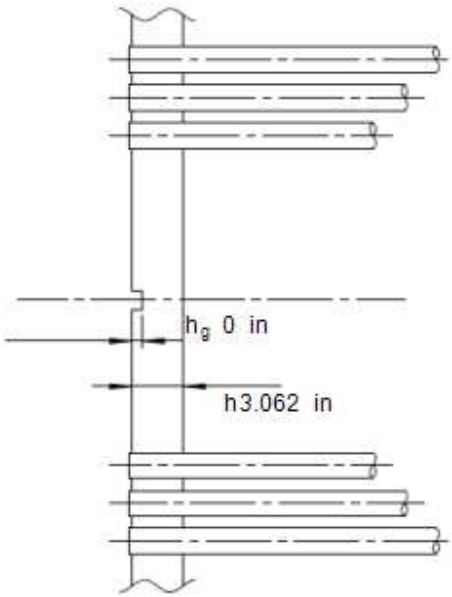
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*649*	



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.95**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*16.63*	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	*1.25*	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	*161.9*	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	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	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}	*510*	°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}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	-
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	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	*37.31*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.255*	in
Gasket factor (Table 2-5.1)	m			*3.75*	
Gasket seating pressure	Y		psi	*7600*	psi
Diameter of gasket force	G		in	***36.81***	in
Poisson's ratio	v	0.3		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**8.821**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.234**	in

Maximum bolt force for all calculation cases	W_{max}	*512937*	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	**366099**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T				E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T				K_{tT}	12000	psi
Tube material allowable stress safety at T				S_{fT}	1	-
Basic ligament efficiency for shear				μ	**0.2**	
Effective tube hole diameter				d*	**0.8946**	in
Effective pitch				p*	**1.25**	in
Effective ligament efficiency for shear				μ*	**0.2843**	
Effective depth of pass partition groove				h_g'	**0**	in
Equivalent radius of outer tube limit circle				a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)				a_c	**18.41**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)				a_s	**17.37**	in
Ratio = ac/a0				ρ_C	**1.075**	
Ratio = as/a0				ρ_S	**1.015**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$				x_s	**0.4467**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$				x_t	**0.6152**	
Type abc: Coefficients for shell pressure				δ_S	**0.1979**	mm^3/N
β_S	**8.523** 1/ft	k_S	**21842** lbf	λ_S	**878462**	psi

Step 2

Shell axial rigidity K_s or K_s*			K_s	**3238266**	lbf/in
Tube axial rigidity			K_t	**37624**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$			K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)			J	**0.003504**	

Step 3

Effective modulus of el. tubesheet	UHX-11.3			E*	**6640243**	psi
Ratio of elasticity tubesheet				E*/E	**0.2607**	
effective Poisson's ratio tubesheet				v*	**0.3653**	
Parameter for table UHX-13.1				X_a	**3.971**	
Z_d **0.02446**	Z_v **0.06398**	Z_m **0.3705**	Z_a **6.611**	Z_w	**0.06398**	

Step 4

Diameter ratio = A/D0			K	**1.182**	
F **0.492**	Φ **0.6718**		Q_1	**-0.02273**	
Q_{z1} **2.859**	Q_{z2} **6.905**		U	**13.81**	

UHX-13.5.5 Step 5, coefficients

γ(*)	**-0.04727** in	ω_S	**2.685** in²	ω_S*	**-2.654**	in²	
ω_C	**0** in²	ω_C*	**9.677** in²	γ_b	**-0.06025**		

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	**-1253**	psi	
P_W	**231.6** psi	P_{rim}	**0** psi	P_e	**-0.4739**	psi	

UHX-13.5.7 Step 7

Q_2	**-3938** lbf	Q_3	**56.65**	F_m	**28.43**

Strength condition for the tubesheet bending stress, case 4

σ =	**8891** psi	< 1.5 · σ_B	= 1.5·	*17952*	psi	case 1-3	
		< S_{PS}	=	*54515*	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau =	**0** psi	< 0.8· σ_B	=	**14362**	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}	**-213.1**		F_{tmax}	**453.5**	
x_{min}	**1.032**		x_{max}	**3.971**	
$\sigma_{T,1}$	**-599.7**	psi	$\sigma_{T,2}$	**1276**	psi

σ_{tmax} = **1276** psi $\leq \sigma_T$ = 12353 psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **24706** psi for calculation case 4-7

Tube weld force W_t = **305.1** lbf $\leq W_{t,all}$ = 0 lbf

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

r_t **0.3255** in F_t **181.2** C_t **1.25** F_s **164.2**

$|\sigma_{tmin}|$ = | **-599.7** psi | $\leq S_{tb}$ = **6123** 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 = *0.1875* in : (calculation case)

$\sigma_{Sm} \leq$ *1·* ***17952*** psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **-21.22** psi $\leq 2 \cdot$ ***17952*** psi = $2 \cdot \sigma_{allS}$ (4-7)

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

-21.22 psi	< Min(**8493** psi , **16996** psi)

ASME external pressure chart CS-2 A = **0.001335**

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

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

σ_{Sm} = psi $\leq 2 \cdot$ psi = $2 \cdot \sigma_{allS}$ (4-7)

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

psi	< Min(psi , psi)

ASME external pressure chart A =

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 = $|\sigma_{Sm}|$ + $|\sigma_{Sb}|$ = **10650** psi $\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}

σ_S = | **-21.22** psi | + | **-10628** psi | ≤ **54515** psi

σ_C = $|\sigma_{Cm}|$ + $|\sigma_{Cb}|$ = **0** psi $\leq 1.5 \cdot \sigma_{allC}$ or S_{PSc}

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

Minimum shell length with uniform thickness l_{Sm} **4.595** 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	**2.547e+7** psi	**2.547e+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 = **10650** psi ≤ ***54515*** 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= *3.062* in < *1* 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
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.79\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 77.79\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.3\ \text{mm} + 25.4\ \text{mm}) = 870\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(31.75\ \text{mm} - 25.4\ \text{mm})}{31.75\ \text{mm}} = 0.2$$

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567122\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6589\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.9\ \text{mm}}{77.79\ \text{mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (870\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{MPa}}{175622\ \text{MPa}} \cdot \frac{85.17\ \text{MPa}}{123.8\ \text{MPa}} \cdot 0.95\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 22.72\ \text{mm}}{22.72\ \text{mm}} = 0.2843$$

5 E4.18.5.O1
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

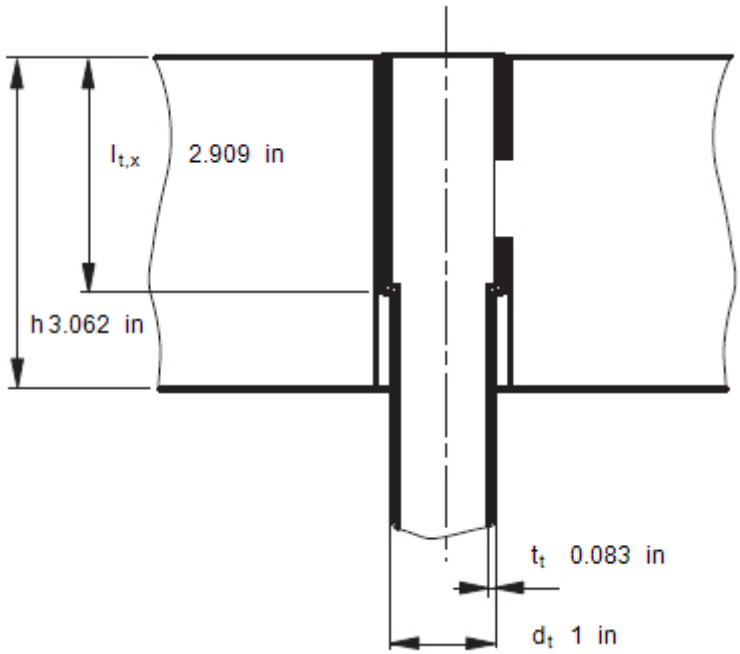
Configuration of the tubesheet (a, b, c, d)	Type	*b*	(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	(1,2)
Internal operation pressure shell side	P_s	*150*	psi
Internal operation pressure tube side	P_t	*400*	psi
Internal 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		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
Young's modulus		*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion		*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength		*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		*17952*	psi	12353	psi	***17952***	psi
Prim.+sec. str.		*54515*	psi			***54515***	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

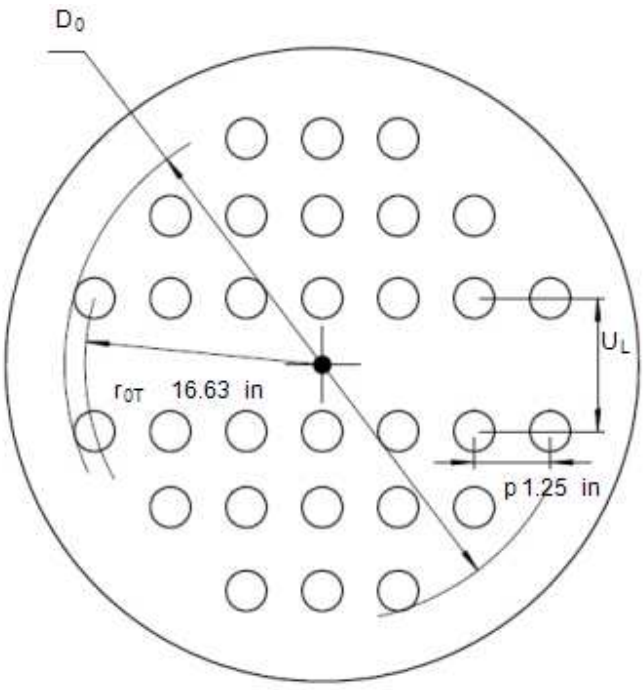
Additional specifications for the geometry and loading

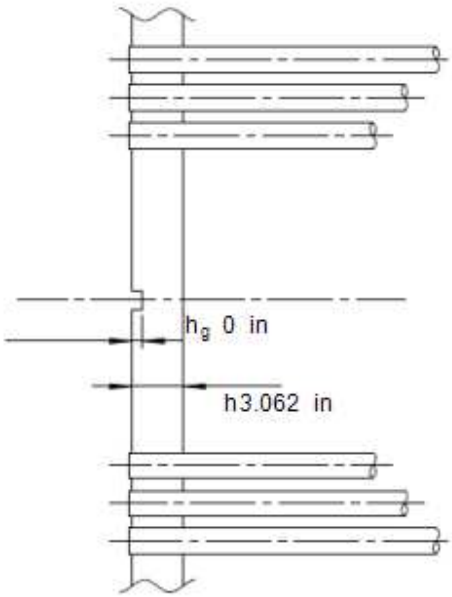
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*649*	



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.95**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*16.63*	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	*1.25*	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	*161.9*	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	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	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}	*510*	°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}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	-
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	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	*37.31*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.255*	in
Gasket factor (Table 2-5.1)	m			*3.75*	
Gasket seating pressure	Y		psi	*7600*	psi
Diameter of gasket force	G		in	***36.81***	in
Poisson's ratio	v	0.3		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512365**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.234**	in

Maximum bolt force for all calculation cases	W_{max}	*512937*	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	**512806**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T				E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T				K_{tT}	12000	psi
Tube material allowable stress safety at T				S_{fT}	1	-
Basic ligament efficiency for shear				μ	**0.2**	
Effective tube hole diameter				d*	**0.8946**	in
Effective pitch				p*	**1.25**	in
Effective ligament efficiency for shear				μ*	**0.2843**	
Effective depth of pass partition groove				h_g'	**0**	in
Equivalent radius of outer tube limit circle				a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)				a_c	**18.41**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)				a_s	**17.37**	in
Ratio = ac/a0				ρ_C	**1.075**	
Ratio = as/a0				ρ_S	**1.015**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$				x_s	**0.4467**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$				x_t	**0.6152**	
Type abc: Coefficients for shell pressure				δ_S	**0.1979**	mm^3/N
β_S	**8.523** 1/ft	k_S	**21842** lbf	λ_S	**878462**	psi

Step 2

Shell axial rigidity K_s or K_s*			K_s	**3238266**	lbf/in
Tube axial rigidity			K_t	**37624**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$			K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)			J	**0.003504**	

Step 3

Effective modulus of el. tubesheet	UHX-11.3				E*	**6640243**	psi
Ratio of elasticity tubesheet					E*/E	**0.2607**	
effective Poisson's ratio tubesheet					v*	**0.3653**	
Parameter for table UHX-13.1					X_a	**3.971**	
Z_d **0.02446**	Z_v **0.06398**	Z_m **0.3705**	Z_a **6.611**		Z_w	**0.06398**	

Step 4

Diameter ratio = A/D0						K	**1.182**
F	**0.492**	Φ	**0.6718**			Q_1	**-0.02273**
Q_{z1}	**2.859**	Q_{z2}	**6.905**			U	**13.81**

UHX-13.5.5 Step 5, coefficients

γ(*)	**-0.04727** in	ω_S	**2.685** in²			ω_S*	**-2.654** in²
ω_C	**0** in²	ω_C*	**9.677** in²			γ_b	**-0.06025**

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'	**861033** psi			P_γ	**-1253** psi
P_W	**231.6** psi	P_{rim}	**182.3** psi			P_e	**-400** psi

UHX-13.5.7 Step 7

Q_2	**-7038** lbf	Q_3	**0.09726**			F_m	**0.0973**

Strength condition for the tubesheet bending stress, case 5

σ =	**25681** psi	< 1.5 · σ_B	= 1.5·	*17952*	psi	case 1-3	
		< S_{PS}	=	*54515*	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau =	**0** psi	< 0.8· σ_B	=	**14362**	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}	**-1.081**		F_{tmax}	**3.813**	
x_{min}	**0**		x_{max}	**3.971**	
$\sigma_{T,1}$	**-4027**	psi	$\sigma_{T,2}$	**7595**	psi

σ_{tmax} = **7595** psi $\leq \sigma_T$ = 12353 psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **24706** psi for calculation case 4-7

Tube weld force W_t = **1816** lbf $\leq W_{t,all}$ = 0 lbf

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

r_t **0.3255** in F_t **181.2** C_t **1.343** F_s **164.2**

$|\sigma_{tmin}|$ = | **-4027** psi | $\leq S_{tb}$ = **5697** 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 = *0.1875* in : (calculation case)

$\sigma_{Sm} \leq$ *1·* ***17952*** psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **0.138** psi $\leq 2 \cdot$ ***17952*** psi = $2 \cdot \sigma_{allS}$ (4-7)

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

0.138 psi	< Min(**8493** psi , **16996** psi)

ASME external pressure chart CS-2 A = **0.001335**

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

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

σ_{Sm} = psi $\leq 2 \cdot$ psi = $2 \cdot \sigma_{allS}$ (4-7)

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

psi	< Min(psi , psi)

ASME external pressure chart A =

Strength condition 13.5.10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **42620** psi $\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}

σ_S = | **0.138** psi | + | **-42620** psi | ≤ **54515** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **0** psi $\leq 1.5 \cdot \sigma_{allC}$ or S_{PSc}

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

Minimum shell length with uniform thickness l_{Sm} **4.595** 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	**2.547e+7** psi	**2.547e+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 = **42620** psi ≤ ***54515*** 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= *3.062* in < *1* 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
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.79\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 77.79\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.3\ \text{mm} + 25.4\ \text{mm}) = 870\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(31.75\ \text{mm} - 25.4\ \text{mm})}{31.75\ \text{mm}} = 0.2$$

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567122\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6589\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.9\ \text{mm}}{77.79\ \text{mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (870\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{MPa}}{175622\ \text{MPa}} \cdot \frac{85.17\ \text{MPa}}{123.8\ \text{MPa}} \cdot 0.95\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 22.72\ \text{mm}}{22.72\ \text{mm}} = 0.2843$$

6 E4.18.5.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	*150*	psi
Internal operation pressure tube side	P_t	*400*	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		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0*	in	*0*	in	*0*	in

Properties for the selected load case temperature

Strength operat.	17952	psi	10430	psi	17952	psi
Safety operation	1		1		1	
Young's modulus	*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion	*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength	*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature	752	°F	752	°F	752	°F
Allow. stress	*17952*	psi	12353	psi	***17952***	psi
Prim.+sec. str.	*54515*	psi			***54515***	psi

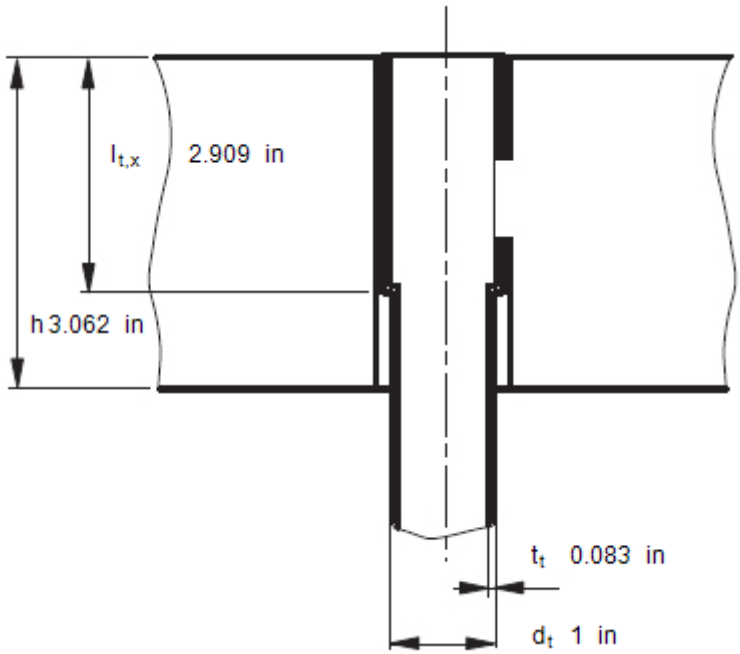
Properties for testing at 20°C

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

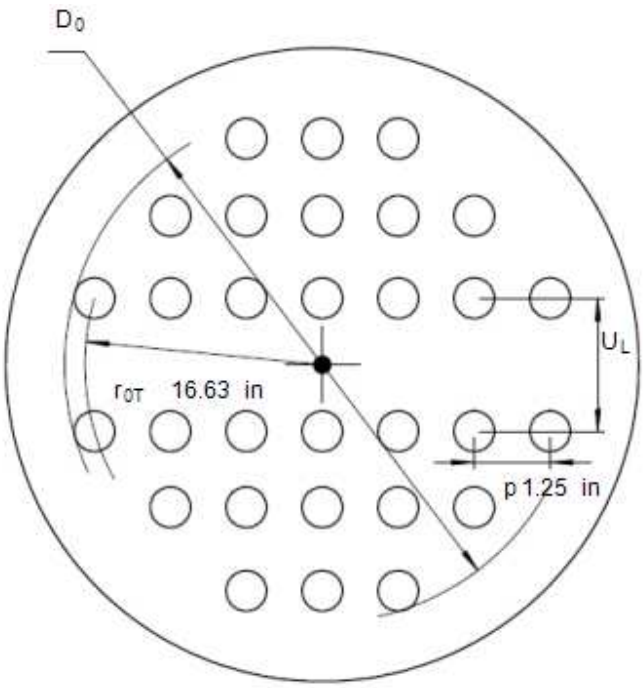
Additional specifications for the geometry and loading

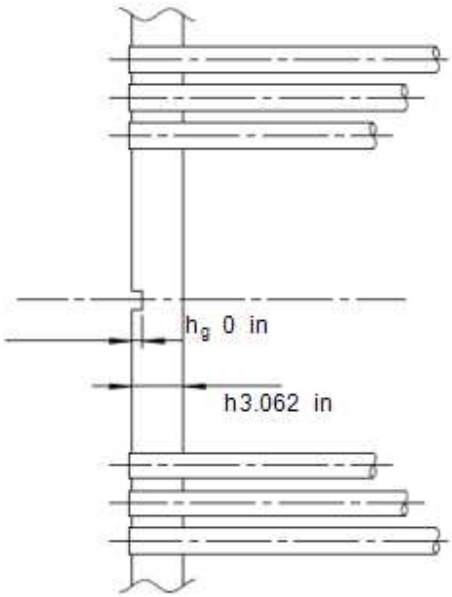
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*649*	



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.95**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*16.63*	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	*1.25*	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	*161.9*	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	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	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}	*510*	°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}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	-
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	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	*37.31*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.255*	in
Gasket factor (Table 2-5.1)	m			*3.75*	
Gasket seating pressure	Y		psi	*7600*	psi
Diameter of gasket force	G		in	***36.81***	in
Poisson's ratio	v	0.3		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**8.821**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.234**	in

Maximum bolt force for all calculation cases	W_{max}	*512937*	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	**366099**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T					E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T					K_{tT}	12000	psi
Tube material allowable stress safety at T					S_{fT}	1	-
Basic ligament efficiency for shear					μ	**0.2**	
Effective tube hole diameter					d*	**0.8946**	in
Effective pitch					p*	**1.25**	in
Effective ligament efficiency for shear					μ*	**0.2843**	
Effective depth of pass partition groove					h_g'	**0**	in
Equivalent radius of outer tube limit circle					a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)					a_c	**18.41**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)					a_s	**17.37**	in
Ratio = ac/a0					ρ_C	**1.075**	
Ratio = as/a0					ρ_S	**1.015**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$					x_s	**0.4467**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$					x_t	**0.6152**	
Type abc: Coefficients for shell pressure					δ_S	**0.1979**	mm^3/N
β_S	**8.523**	1/ft	k_S	**21842** lbf	λ_S	**878462**	psi

Step 2

Shell axial rigidity K_s or K_s*					K_s	**3238266**	lbf/in
Tube axial rigidity					K_t	**37624**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$					K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)					J	**0.003504**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3			E*	**6640243**	psi
Ratio of elasticity tubesheet					E*/E	**0.2607**	
effective Poisson's ratio tubesheet					v*	**0.3653**	
Parameter for table UHX-13.1					X_a	**3.971**	
Z_d	**0.02446**	Z_v	**0.06398**	Z_m **0.3705** Z_a **6.611**	Z_w	**0.06398**	

Step 4

Diameter ratio = A/D0					K	**1.182**	
F	**0.492**	Φ	**0.6718**		Q_1	**-0.02273**	
Q_{z1}	**2.859**	Q_{z2}	**6.905**		U	**13.81**	

UHX-13.5.5 Step 5, coefficients

γ(*)	**-0.04727**	in	ω_S	**2.685** in²	ω_S*	**-2.654**	in²
ω_C	**0**	in²	ω_C*	**9.677** in²	γ_b	**-0.06025**	

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'	**-46334**	psi	P_t'	**0** psi	P_γ	**-1253**	psi
P_W	**231.6**	psi	P_{rim}	**18.74** psi	P_e	**-21.97**	psi

UHX-13.5.7 Step 7

Q_2	**-4257**	lbf	Q_3	**1.299**	F_m	**0.6701**	

Strength condition for the tubesheet bending stress, case 6

σ =	**9714**	psi	< 1.5 · σ_B	= 1.5·	*17952*	psi	case 1-3
			< S_{PS}	=	*54515*	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau =	**0**	psi	< 0.8· σ_B	=	**14362**	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}	-5.51		F_{tmax}	13.37	
x_{min}	0.3971		x_{max}	3.971	
$\sigma_{T,1}$	-320.8	psi	$\sigma_{T,2}$	2141	psi

σ_{tmax} = 2141 psi $\leq \sigma_T$ = 12353 psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = 24706 psi for calculation case 4-7

Tube weld force W_t = 512 lbf $\leq W_{t,all}$ = 0 lbf

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

r_t 0.3255 in F_t 181.2 C_t 1.25 F_s 164.2

$|\sigma_{tmin}|$ = | -320.8 psi | $\leq S_{tb}$ = 6123 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 = *0.1875* in : (calculation case)

$\sigma_{Sm} \leq$ *1·* ***17952*** psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = -786 psi $\leq 2 \cdot$ ***17952*** psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| -786 psi | < Min(8493 psi , 16996 psi)

ASME external pressure chart CS-2 A = 0.001335

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

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

σ_{Sm} = psi $\leq 2 \cdot$ psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 13.5.10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = 9364 psi $\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}

σ_S = | -786 psi | + | 8578 psi | ≤ 54515 psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = 0 psi $\leq 1.5 \cdot \sigma_{allC}$ or S_{PSc}

σ_C = | 0 psi | + | 0 psi | ≤ 0 psi

Minimum shell length with uniform thickness l_{Sm} 4.595 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	**2.547e+7** psi	**2.547e+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 = **9364** psi ≤ ***54515*** 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= *3.062* in < *1* 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
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.79\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 77.79\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.3\ \text{mm} + 25.4\ \text{mm}) = 870\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(31.75\ \text{mm} - 25.4\ \text{mm})}{31.75\ \text{mm}} = 0.2$$

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567122\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6589\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.9\ \text{mm}}{77.79\ \text{mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (870\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{MPa}}{175622\ \text{MPa}} \cdot \frac{85.17\ \text{MPa}}{123.8\ \text{MPa}} \cdot 0.95\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 22.72\ \text{mm}}{22.72\ \text{mm}} = 0.2843$$

7 E4.18.5.O3
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

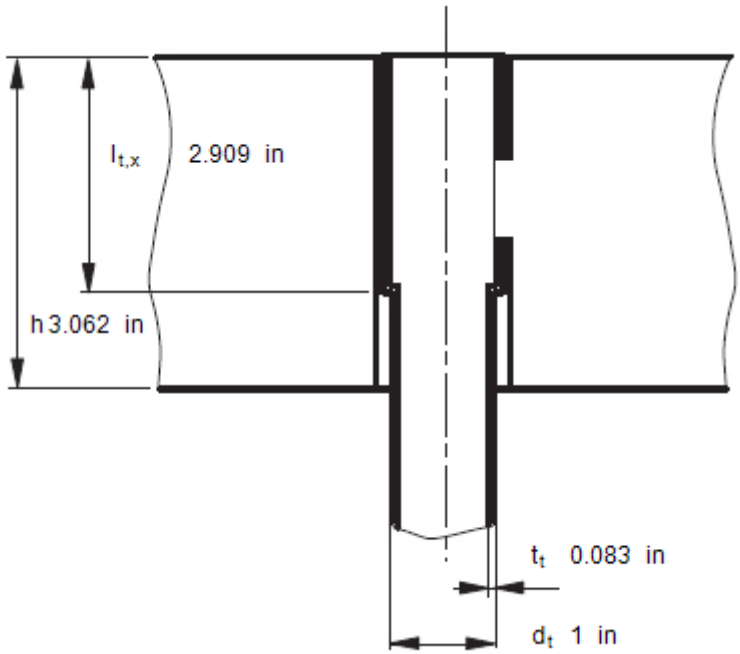
Configuration of the tubesheet (a, b, c, d)	Type	*b*	(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	(1,2)
Internal operation pressure shell side	P_s	*150*	psi
Internal operation pressure tube side	P_t	*400*	psi
Internal 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		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
Young's modulus		*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion		*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength		*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		*17952*	psi	12353	psi	***17952***	psi
Prim.+sec. str.		*54515*	psi			***54515***	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

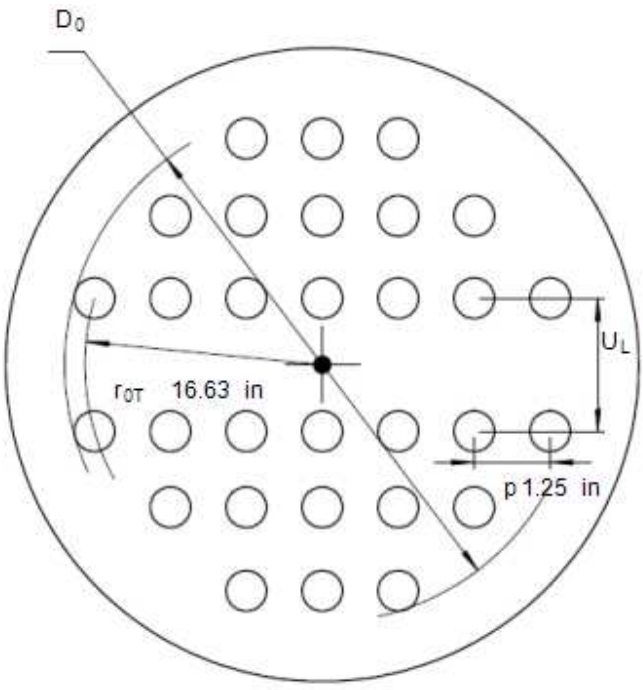
Additional specifications for the geometry and loading

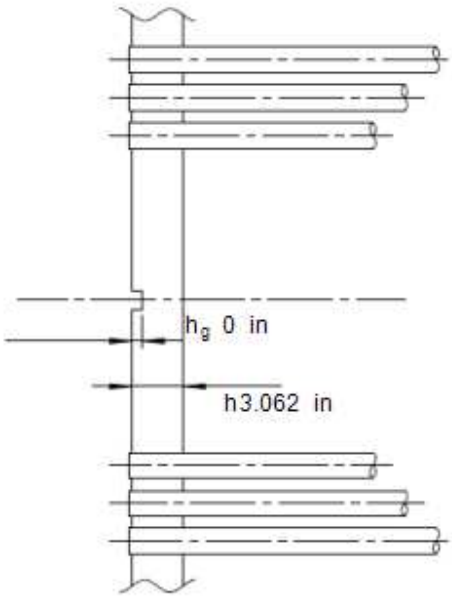
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*649*	



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.95**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*16.63*	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	*1.25*	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	*161.9*	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	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	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}	*510*	°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}	*7.3*	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	-
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	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	*37.31*	in
Contact inside diameter	G_i		in		in
Basic seating width	b_0		in	*0.255*	in
Gasket factor (Table 2-5.1)	m			*3.75*	
Gasket seating pressure	Y		psi	*7600*	psi
Diameter of gasket force	G		in	***36.81***	in
Poisson's ratio	v	0.3		*0.3*	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512365**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.234**	in

Maximum bolt force for all calculation cases	W_{max}	*512937*	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	**512806**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T				E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T				K_{tT}	12000	psi
Tube material allowable stress safety at T				S_{fT}	1	-
Basic ligament efficiency for shear				μ	**0.2**	
Effective tube hole diameter				d*	**0.8946**	in
Effective pitch				p*	**1.25**	in
Effective ligament efficiency for shear				μ*	**0.2843**	
Effective depth of pass partition groove				h_g'	**0**	in
Equivalent radius of outer tube limit circle				a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)				a_c	**18.41**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)				a_s	**17.37**	in
Ratio = ac/a0				ρ_C	**1.075**	
Ratio = as/a0				ρ_S	**1.015**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$				x_s	**0.4467**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$				x_t	**0.6152**	
Type abc: Coefficients for shell pressure				δ_S	**0.1979**	mm^3/N
β_S	**8.523** 1/ft	k_S	**21842** lbf	λ_S	**878462**	psi

Step 2

Shell axial rigidity K_s or K_s*			K_s	**3238266**	lbf/in
Tube axial rigidity			K_t	**37624**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$			K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)			J	**0.003504**	

Step 3

Effective modulus of el. tubesheet	UHX-11.3			E*	**6640243**	psi
Ratio of elasticity tubesheet				E*/E	**0.2607**	
effective Poisson's ratio tubesheet				v*	**0.3653**	
Parameter for table UHX-13.1				X_a	**3.971**	
Z_d **0.02446**	Z_v **0.06398**	Z_m **0.3705**	Z_a **6.611**	Z_w	**0.06398**	

Step 4

Diameter ratio = A/D0			K	**1.182**	
F **0.492**	Φ **0.6718**		Q_1	**-0.02273**	
Q_{z1} **2.859**	Q_{z2} **6.905**		U	**13.81**	

UHX-13.5.5 Step 5, coefficients

γ(*)	**-0.04727** in	ω_S	**2.685** in²	ω_S*	**-2.654**	in²	
ω_C	**0** in²	ω_C*	**9.677** in²	γ_b	**-0.06025**		

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'	**-46334**	psi	P_t'	**861033**	psi	P_γ	**-1253**	psi
P_W	**231.6**	psi	P_{rim}	**201**	psi	P_e	**-421.5**	psi

UHX-13.5.7 Step 7

Q_2	**-7356** lbf	Q_3	**0.0963**	F_m	**0.09692**

Strength condition for the tubesheet bending stress, case 7

σ =	**26955**	psi	$< 1.5\cdot\sigma_B$ =	1.5·	*17952*	psi	case 1-3
			$< S_{PS}$ =		*54515*	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau =	**0** psi	$< 0.8\cdot\sigma_B$ =		**14362**	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}	**-1.077**		F_{tmax}	**3.806**	
x_{min}	**0**		x_{max}	**3.971**	
$\sigma_{T,1}$	**-3758**	psi	$\sigma_{T,2}$	**8461**	psi

σ_{tmax} = **8461** psi $\leq \sigma_T$ = 12353 psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **24706** psi for calculation case 4-7

Tube weld force W_t = **2023** lbf $\leq W_{t,all}$ = 0 lbf

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

r_t **0.3255** in F_t **181.2** C_t **1.347** F_s **164.2**

$|\sigma_{tmin}|$ = | **-3758** psi | $\leq S_{tb}$ = **5681** 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 = *0.1875* in : (calculation case)

$\sigma_{Sm} \leq$ *1·* ***17952*** psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **-764.7** psi $\leq 2 \cdot$ ***17952*** psi = $2 \cdot \sigma_{allS}$ (4-7)

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

|	**-764.7**	psi	| < Min(	**8493**	psi ,	**16996**	psi)

ASME external pressure chart CS-2 A = **0.001335**

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

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

σ_{Sm} = psi $\leq 2 \cdot$ psi = $2 \cdot \sigma_{allS}$ (4-7)

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

|		psi	| < Min(		psi ,		psi)

ASME external pressure chart A =

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 =	$\|\sigma_{Sm}\|$ +	$\|\sigma_{Sb}\|$ =		**24177**	psi	$\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}			
σ_S =	|	**-764.7**	psi | + |	**-23413**	psi	| ≤	**54515**	psi	
σ_C =	$\|\sigma_{Cm}\|$ +	$\|\sigma_{Cb}\|$ =		**0**	psi	$\leq 1.5 \cdot \sigma_{allC}$ or S_{PSc}			
σ_C =	|	**0**	psi | + |	**0**	psi	| ≤	**0**	psi	

Minimum shell length with uniform thickness l_{Sm} **4.595** 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	**2.547e+7** psi	**2.547e+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 = **24177** psi ≤ ***54515*** 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= *3.062* in < *1* 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
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.79\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 77.79\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.3\ \text{mm} + 25.4\ \text{mm}) = 870\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(31.75\ \text{mm} - 25.4\ \text{mm})}{31.75\ \text{mm}} = 0.2$$

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567122\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6589\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.9\ \text{mm}}{77.79\ \text{mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (870\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{MPa}}{175622\ \text{MPa}} \cdot \frac{85.17\ \text{MPa}}{123.8\ \text{MPa}} \cdot 0.95\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 22.72\ \text{mm}}{22.72\ \text{mm}} = 0.2843$$

8 E4.18.5.D1-plastic
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

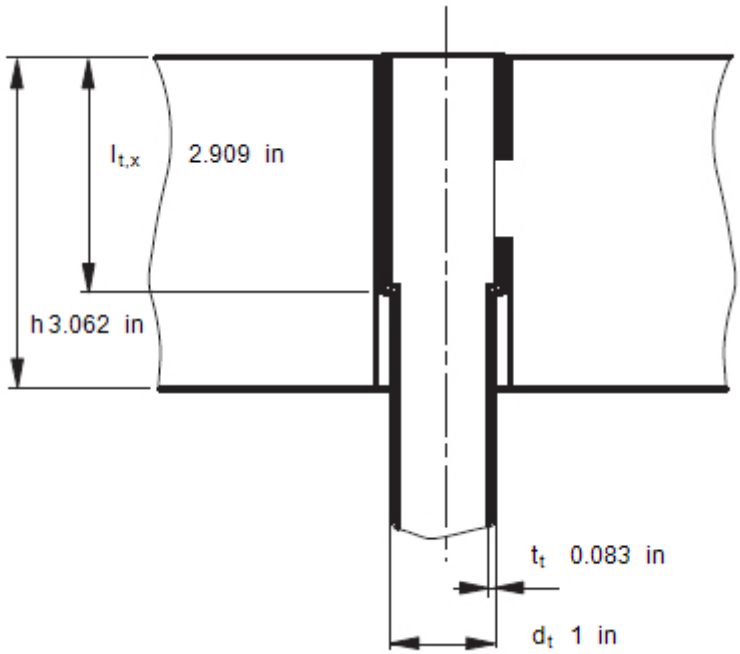
Configuration of the tubesheet (a, b, c, d)		Type	b	(a-d)
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)			1	(1,2)
Internal operation pressure shell side		P_s	150	psi
Internal operation pressure tube side		P_t	400	psi
Internal test 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		700	°F	700	°F	700	°F
Thickness		3.062	in	0.083	in	0.1875	in
Outside diameter		40.5	in	1	in	**35.13**	in
Poisson's ratio		-		0.3		0.3	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	0	in	0	in	0	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		0.85		1	
Young's modulus		2.547e+7	psi	2.547e+7	psi	2.547e+7	psi
Thermal expansion		7.586	1E-6/°F	7.586	1E-6/°F	7.586	1E-6/°F
Yield strength		27257	psi	18655	psi	27257	psi
Limit temperature		752	°F	752	°F	752	°F
Allow. stress		**17952**	psi	**12271**	psi	**17952**	psi
Prim.+sec. str.		**54515**	psi			**54515**	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

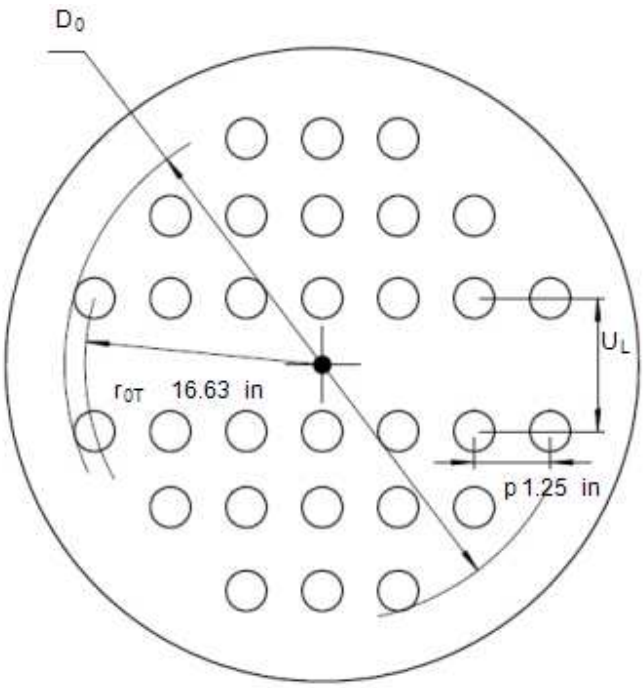
Additional specifications for the geometry and loading

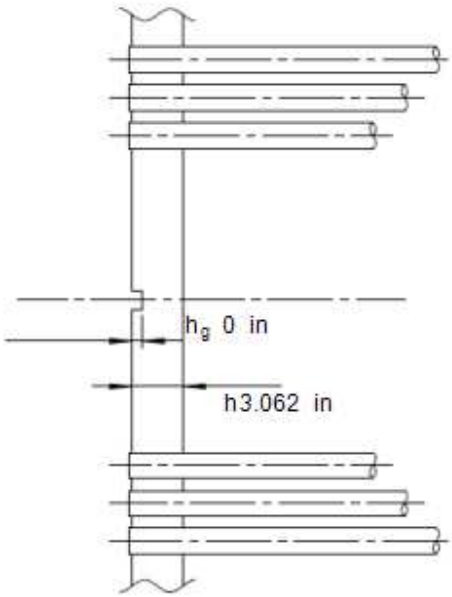
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		1	(1, 2)
Number of tubes		N_t	649	



Expanded length of tube in tubesheet		$l_{t,x}$	**2.909**	in
Expanded length ratio $l_{t,x}$/h		ρ	0.95	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63	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	1.25	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	161.9	in
Unsupported tube span for buckling	l	59	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	**59**	in
Bellows inside diameter at its convolution height	D_j	38.5	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	11388	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}	510	°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}	7.274	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	38.88	in
Number of bolts	n	68	-
Bolt root diameter	d_B	0.62	in
Total bolt area	A_b	**20.53**	in²
Bolt material G41400-SA-193-B7-Class:-Size:<=64			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	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	37.31	in
Contact inside diameter	G_i		in	36.31	in
Basic seating width	b_0		in	0.255	in
Gasket factor (Table 2-5.1)	m			3.75	
Gasket seating pressure	Y		psi	7600	psi
Diameter of gasket force	G		in	**36.81**	in
Poisson's ratio	v	0.3		0.3	

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512365**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.234**	in

Maximum bolt force for all calculation cases	W_{max}	512937	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	**512806**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	34.75	in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T				E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T				K_{tT}	12000	psi
Tube material allowable stress safety at T				S_{fT}	1	-
Basic ligament efficiency for shear				μ	**0.2**	
Effective tube hole diameter				d*	**0.8946**	in
Effective pitch				p*	**1.25**	in
Effective ligament efficiency for shear				μ*	**0.2843**	
Effective depth of pass partition groove				h_g'	**0**	in
Equivalent radius of outer tube limit circle				a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)				a_c	**18.41**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)				a_s	**17.38**	in
Ratio = ac/a0				ρ_C	**1.075**	
Ratio = as/a0				ρ_S	**1.015**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$				x_s	**0.4467**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$				x_t	**0.6152**	
Type abc: Coefficients for shell pressure				δ_S	**0.1979**	mm^3/N
β_S	**8.523** 1/ft	k_S	**21842** lbf	λ_S	**878462**	psi

Step 2

Shell axial rigidity K_s or K_s*			K_s	**3238266**	lbf/in
Tube axial rigidity			K_t	**37624**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$			K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)			J	**0.003504**	

Step 3

Effective modulus of el. tubesheet	UHX-11.3				E*	**6640239**	psi
Ratio of elasticity tubesheet					E*/E	**0.2607**	
effective Poisson's ratio tubesheet					v*	**0.3653**	
Parameter for table UHX-13.1					X_a	**3.971**	
Z_d **0.02446**	Z_v **0.06398**	Z_m **0.3705**	Z_a **6.611**		Z_w	**0.06398**	

Step 4

Diameter ratio = A/D0						K	**1.182**
F	**0.492**	Φ	**0.6718**			Q_1	**-0.02273**
Q_{z1}	**2.859**	Q_{z2}	**6.905**			U	**13.81**

UHX-13.5.5 Step 5, coefficients

γ(*)	**0** in	ω_S	**2.685**	in²	ω_S*	**-2.654**	in²
ω_C	**0** in²	ω_C*	**9.677**	in²	γ_b	**-0.06025**	

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'	**861033**	psi	P_γ	**0**	psi
P_W	**231.6** psi	P_{rim}	**182.3**	psi	P_e	**-399.4**	psi

UHX-13.5.7 Step 7

Q_2	**-7038** lbf	Q_3	**0.09743**	F_m	**0.09737**

Strength condition for the tubesheet bending stress, case 1

σ =	**25662**	psi	< 1.5 · σ_B =	1.5·	**17952**	psi	case 1-3
			< S_{PS} =		**54515**	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau =	**0** psi	< 0.8· σ_B =		**14362**	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}	-1.081		F_{tmax}	3.815	
x_{min}	0		x_{max}	3.971	
$\sigma_{T,1}$	-4025	psi	$\sigma_{T,2}$	7585	psi

σ_{tmax} = 7585 psi $\leq \sigma_T$ = 12271 psi for calculation case 1-3
$\leq 2 \cdot \sigma_T$ = 24541 psi for calculation case 4-7

Tube weld force W_t = 1814 lbf $\leq W_{t,all}$ = 0 lbf
(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t 0.3255 in F_t 181.2 C_t 1.343 F_s 164.2

$|\sigma_{tmin}|$ = | -4025 psi | $\leq S_{tb}$ = 5700 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 = 0.1875 in : (calculation case)
$\sigma_{Sm} \leq$ 1· 17952 psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)
σ_{Sm} = 26.16 psi $\leq$2· 17952 psi = $2 \cdot \sigma_{allS}$ (4-7)

For σSm < 0: $|\sigma_{Sm}|$ < Min(B, A·E/2) acc. UG-23(b)
| 26.16 psi | < Min(8493 psi , 16996 psi)
ASME external pressure chart CS-2 A = 0.001335

Region of increased thickness t_{1s} = in : (calculation case)
$\sigma_{Sm} \leq$ 1· psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)
σ_{Sm} = psi $\leq$2· psi = $2 \cdot \sigma_{allS}$ (4-7)

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

Strength condition 13.5.10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = 42611 psi $\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}
σ_S = | 26.16 psi | + | -42585 psi | ≤ 26929 psi
$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = 0 psi $\leq 1.5 \cdot \sigma_{allC}$ or S_{PSc}
σ_C = | 0 psi | + | 0 psi | ≤ 0 psi

Minimum shell length with uniform thickness l_{Sm} 4.595 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	**2.547e+7** psi	**2.547e+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 = **42611** psi ≤ **54515** 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

13.4(d) If: Tube sheet thickness= 3.062 in < 1 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
54515 psi = 3· **17952** psi or 2· 27257 psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 752 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.79\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 77.79\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.3\ \text{mm} + 25.4\ \text{mm}) = 870\ \text{mm}$$

$$\mu = \frac{(p - d_{aT})}{p} = \frac{(31.75\ \text{mm} - 25.4\ \text{mm})}{31.75\ \text{mm}} = 0.2$$

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567122\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6589\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.9\ \text{mm}}{77.79\ \text{mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (870\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{MPa}}{175622\ \text{MPa}} \cdot \frac{84.6\ \text{MPa}}{123.8\ \text{MPa}} \cdot 0.95\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 22.72\ \text{mm}}{22.72\ \text{mm}} = 0.2843$$

9 Table
Form for equations

Tables

with comment every three lines

Arrangement in 3 lines. Line 3 calculates the difference between line 1 and 2 in %. The maximum of each line is calculated in column 8 at the end.

	Conversion factors			Step 1-3			Maximum
	MPa2psi	N2lb	mm2in	hr	my*	Kst	J	Diff %
1	145	0.2248	0.03937	1.233	0.2843	0.1326	0.003504	
2	0	0	0	1.228	0.2861	0.1326	0.0035	
3	0	0	0	0.4478	0.6187	0.001885	0.125	0.6187

---- Step 2 ----

	betaS	kS	lambdaS	deltaS	betaC	kc	lambdaC	MaxDiff%
4	0.7102	21841	878238	5.373e-5	0	0	0	
5	0.7102	21866	879437	5.367e-5	0	0	0	
6	0.006745	0.1164	0.1363	0.114	0	0	0	0.1363

---- Step 3 ----

	ny*	E*	Xa	Zd	Zv	Zm	Za	MaxDiff%
7	0.3653	6638545	3.971	0.02446	0.06398	0.3705	6.611	
8	0.364	6706322	3.963	0.02461	0.06426	0.3715	6.547	
9	0.3794	1.011	0.1909	0.5934	0.4276	0.2606	0.9643	1.011

---- Step 4 ----

	K	F	phi	Q1	Qz1	Qz2	U	MaxDiff%
10	1.182	0.492	0.6718	-0.02273	2.859	6.905	13.81	
11	1.183	0.4888	0.6667	-0.02263	2.856	6.888	13.78	
12	0.001522	0.6588	0.7618	0.4104	0.1327	0.2485	0.2485	0.7618

---- Step 5 ----

	omS	om*S	omC	om*C	gammab			MaxDiff%
13	2.685	-2.654	0	9.677	-0.06025			
14	2.685	-2.654	0	9.682	-0.06022			
15	0.00149	0.00147	0	0.05101	0.04598	0	0	0.05101

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

	gamma	Ps'	Pt'	Pgamma	PW	Prim	Pe	MaxDiff%
16	-0.04727	-46322	860814	-1252	231.6	201	-421.4	
17	-0.047	-46387	862002	-1254	230.9	200.6	-421.5	
18	0.5693	0.14	0.1379	0.1231	0.2825	0.1835	0.02733	0.5693

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

	Q2	Q3	Fm	|Sig|	|Tau|	Ftmin	Sigt1	MaxDiff%
19	-7037	0.09743	0.09737	25656		-1.081	-4024	
20	-7041	0.0976	0.0975	25540		-1.081	-4024	
21	0.04914	0.1718	0.1319	0.453		0.01434	0.007331	10.453

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

	Q2	Q3	Fm	|Sig|	|Tau|	Ftmin	Sigt1	MaxDiff%
22	-318.7	0.07875	0.09004	1272		-1.012	269.1	
23	-319	0.0786	0.0901	-1269		-1.011	-269	
24	-0.09373	0.1949	-0.06574	0.2504		0.1316	0.02093	0.2504

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

	Q2	Q3	Fm	|Sig|	|Tau|	Ftmin	Sigt1	MaxDiff%
25	-7356	0.09646	0.09699	26929		-1.078	-3755	
26	-7363	0.09667	0.09717	26819		-1.078	-3758	
27	0.09987	0.2173	0.1902	0.4106		0.0397	0.07611	0.4106

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

	Q2	Q3	Fm	|Sig|	|Tau|	Ftmin	Sigt1	MaxDiff%
28	-3938	56.65	28.43	8888		-213.1	-599.6	
29	-3940	56.63	28.41	8838		-213.2	-600.4	
30	0.05713	0.03625	0.07466	0.5686		0.02388	0.1412	0.5686

Links

```
1   1 UHXb: MPa2psi = 145: N2lb = 0.2248: mm2in=0.03937: #299*mm2in: #88: #198: #113
2   9 EQU: : : : 1.228: 0.2861: 0.13262: 0.0035
3
4   2 UHXb: #121/mm2in: #122*N2lb: #123*MPa2psi: #124*mm2in^3/N2lb: #126/mm2in: #127*N2lb: #128*MPa2psi
5   9 EQU: 0.7102: 21866: 879437: 0.0000536694: : :
6
7   1 UHXb: #100: #98*MPa2psi: #120: #203: #204: #205: #304
8   9 EQU: 0.363967: 6706322: 3.9630: 0.024609: 0.064259: 0.371462:6.54740
9
10  1 UHXb: #131: #132: #206: #207: #208: #209: #210
11  9 EQU: 1.1825: 0.4888: 0.6667: -0.022635: 2.8556: 6.888: 13.776
12
13  1 UHXb: #125*mm2in^2: #136*mm2in^2: #130*mm2in^2: #135*mm2in^2: #134
14  9 EQU: 2.685: -2.6536: 0 : 9.6816: -0.06022
15

16  7 UHXb: #137*mm2in: #255*MPa2psi: #256*MPa2psi: #257*MPa2psi: #258*MPa2psi: #259*MPa2psi: #260*MPa2psi
17  9 EQU: -0.047: -46387: 862002: -1254: 230.9: 200.6: -421.5
18
19  1 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
20  9 EQU: -7040.7: 0.0976: 0.0975: 25540: 5584: -1.081: -4024
21
22  2 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
23  9 EQU: -319: 0.0786: 0.0901: -1269: 299: -1.011: -269
24
25  3 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
26  9 EQU: -7363.3: 0.09667: 0.09717: 26819: 5884.2: -1.078: -3757.8
27
28  4 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
29  9 EQU: -3940.3: 56.627: 28.409: 8838: 6.6: -213.188: -600.4
30
```

Additional comments

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

10 Table
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.5 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	-7037	0.09726	0.0973	25675		-1.081	-4026	
5	-7044	0.09746	0.09749	25569		-1.081	-4029	
6	-0.09873	-0.2076	-0.1928	0.4134		-0.04514	-0.07178	0.4134

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

	Q2 :	Q3 :	Fm :	|Sig| :	|Tau| :	Ftmin :	Sigt1 :	MaxDiff%
7	-4257	1.299	0.6701	9712		-5.51	-320.7	
8	-4259	1.299	0.6705	9658		-5.52	-322.2	
9	-0.05987	-0.02071	-0.04795	0.5585		-0.1896	-0.4738	0.558

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

	Q2 :	Q3 :	Fm :	|Sig| :	|Tau|	Ftmin :	Sigt1 :	MaxDiff%
10	-7356	0.0963	0.09692	26948		-1.077	-3757	
11	-7363	0.0965	0.09711	26839		-1.078	-3760	
12	-0.09987	-0.2119	-0.1958	0.4067		-0.09583	-0.07598	0.4067

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

	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSb :	
13	3.815	7583	-4024	1.343	5699	26.16	-42574	0
14	3.809	7571	4027	1.346	5694	26.1	-42464	
15	0.1536	0.1643	-0.0719	-0.2545	0.08917	0.2218	0.2601	0.2601

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

	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSb :	
16	3.666	863.8	269.1	1.417	5400	-761.2	19207	0
17	3.658	865	320.1	1.25	6129	-760	19214	
18	0.2275	-0.1338	-15.95	13.35	-11.9	0.1525	-0.03846	0.2275

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

	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSb :	
19	3.807	8449	-3755	1.346	5683	-738.4	-23372	0
20	3.801	8436	3755	1.349	5678	-738.7	-23227	
21	0.161	0.1528	-1.6e-3	-0.1897	0.08826	-0.03556	0.626	0.626

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

	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSb :
22	453.5	1276	-599.6	1.25	6121	-21.21	-10626	0
23	451.8	1272	600.4	1.25	6129	-21.2	-10590	
24	0.3712	0.2535	-0.1412	0	-0.1364	0.0533	0.3378	0.3712

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

	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm(*):	SigSb :
25	3.813	7593	-4026	1.343	5696	0.138	-42609	0
26	3.807	7581	4024	1.346	5691	0.0579	-42484	
27	0.1697	0.1637	0.04742	-0.2029	0.09013	0	0.2939	0.2939

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

	Ftmax :	Sigt,2 :	Sigt,min:	Fs :	Stb :	SigSm :	SigSb :
28	13.37	2141	-320.7	1.25	6121	-785.8	8576	0
29	13.33	2137	322.2	1.25	6129	786.1	8633	
30	0.2479	0.1765	-0.4738	0	-0.1364	-0.03701	-0.6569	0.6569

Links

1 1 UHXb: MPa2psi = 145: N2lb = 0.2248: mm2in=0.03937: : : :
2 10 EQU: : : : : : :
3
4 5 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
5 10 EQU: -7044.2: 0.09746: 0.09749: 25569: 5591.8: -1.081: -4028.8
6
7 6 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
8 10 EQU: -4259.3: 1.299: 0.67047: 9658: 307.1: -5.520: -322.2
9
10 7 UHXb: #153*N2lb: #133: #261: #138*MPa2psi: #140*MPa2psi: #305: #311*MPa2psi
11 10 EQU: -7363.3: 0.09650: 0.09711: 26839: 5892.3: -1.078: -3760
12
13 1 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #143*MPa2psi:
14 10 EQU: 3.809: 7571: 4026.6: 1.346: 5693.9: 26.1: -42464
15

16 2 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #143*MPa2psi:
17 10 EQU: 3.658: 865: 320.1: 1.25: 6129.4: -760: 19214
18
19 3 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #143*MPa2psi:
20 10 EQU: 3.801: 8435.7: 3755: 1.349: 5677.6: -738.7: -23227
21
22 4 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #143*MPa2psi:
23 10 EQU: 451.8: 1272.4: 600.4: 1.25: 6129.4: -21.2: -10590
24
25 5 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #143*MPa2psi:
26 10 EQU: 3.807: 7580.9: 4024: 1.346: 5690.9: 0.0579: -42484
27
28 6 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #143*MPa2psi:
29 10 EQU: 13.334: 2137: 322.2: 1.25: 6129.4: 786.1: 8633
30

Additional comments

11 Table
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.5 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 9+10+11, calculation case 7(O3) ----------								
	Ftmax :	Sigt,2 :	Sigt,min:		Fs :	Stb :	SigSm :	SigSb :
4	3.806	8458	-3757	1.347	5680	-764.5	-23407	0
5	3.76	8446	3760	1.35	5675	-764.8	-23271	
6	1.218	0.1534	-0.07598	-0.2152	0.08728	-0.04438	0.5836	1.218
--- |Sig| for UHX-20.2.1(c)(12) plastic calculation ----------								
7	25656	0	0	0	0	0	0	
8	25752	0	0	0	0	0	0	
9	-0.374	0	0	0	0	0	0	0.374

Links

1 1 UHXb: MPa2psi = 145: N2lb = 0.2248: mm2in=0.03937: : : :
2 11 EQU: : : : : : :
3
4 7 UHXb: #306: #312*MPa2psi: #315*MPa2psi: #268: #269*MPa2psi: #319*MPa2psi: #143*MPa2psi:
5 11 EQU: 3.76: 8445.5: 3760: 1.35: 5674.9: -764.8: -23271
6
7 8 UHXb: #138(8)*MPa2psi
8 11 EQU: 25752

Appendix: Material documentation

Section 1: Boden/UHXb
Section 1: Mantel/UHXb
Section 1: Boden-Zeitst/UHXb
Section 1: Mantel-Zeitst/UHXb
Section 2: Boden/UHXb
Section 2: Mantel/UHXb
Section 2: Boden-Zeitst/UHXb
Section 2: Mantel-Zeitst/UHXb
Section 3: Boden/UHXb
Section 3: Mantel/UHXb
Section 3: Boden-Zeitst/UHXb
Section 3: Mantel-Zeitst/UHXb
Section 4: Boden/UHXb
Section 4: Mantel/UHXb
Section 4: Boden-Zeitst/UHXb
Section 4: Mantel-Zeitst/UHXb
Section 5: Boden/UHXb
Section 5: Mantel/UHXb
Section 5: Boden-Zeitst/UHXb
Section 5: Mantel-Zeitst/UHXb
Section 6: Boden/UHXb
Section 6: Mantel/UHXb
Section 6: Boden-Zeitst/UHXb
Section 6: Mantel-Zeitst/UHXb
Section 7: Boden/UHXb
Section 7: Mantel/UHXb
Section 7: Boden-Zeitst/UHXb
Section 7: Mantel-Zeitst/UHXb
Section 8: Boden/UHXb
Section 8: Mantel/UHXb
Section 8: Boden-Zeitst/UHXb
Section 8: 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]:	371,1111	Pressure [bar]:	0
Thickness [mm]:	77,79	Outside diameter [mm]:	1028,7

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	123,78
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	123,78
Modulus of elasticity [kN/mm²]:	202	175,6222

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 1: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 2: Rohre/UHXb
Section 2: Rohre-Zeitst/UHXb
Section 2: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 3: Rohre/UHXb
Section 3: Rohre-Zeitst/UHXb
Section 3: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 4: Rohre/UHXb
Section 4: Rohre-Zeitst/UHXb
Section 4: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 5: Rohre/UHXb
Section 5: Rohre-Zeitst/UHXb
Section 5: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 6: Rohre/UHXb
Section 6: Rohre-Zeitst/UHXb
Section 6: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 7: Rohre/UHXb
Section 7: Rohre-Zeitst/UHXb
Section 7: Rohre bei Bodentemp. /Tubes at tubesheet temp./UHXb
Section 8: Rohre/UHXb
Section 8: Rohre-Zeitst/UHXb
Section 8: 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]: 371,1111 Pressure [bar]: 0
Thickness [mm]: 2,11 Outside diameter [mm]: 25,4

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	78,60	71,91
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	78,60	71,91
Modulus of elasticity [kN/mm²]:	202	175,6222

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: mittlere W-dehn. Mantel/UHXb
Section 2: mittlere W-dehn. Mantel/UHXb
Section 3: mittlere W-dehn. Mantel/UHXb
Section 4: mittlere W-dehn. Mantel/UHXb
Section 5: mittlere W-dehn. Mantel/UHXb
Section 6: mittlere W-dehn. Mantel/UHXb
Section 7: mittlere W-dehn. Mantel/UHXb
Section 8: mittlere W-dehn. Mantel/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]: 287,78 Pressure [bar]: 0
Thickness [mm]: 4,76 Outside diameter [mm]: 892,18

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

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]: 265,56 Pressure [bar]: 0
Thickness [mm]: 2,11 Outside diameter [mm]: 25,4

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	78,60	78,44
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	78,60	78,44
Modulus of elasticity [kN/mm²]:	202	187,7552

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: Bodenrand-3/UHXb
Section 1: Schale-Rand-3/UHXb
Section 2: Bodenrand-3/UHXb
Section 2: Schale-Rand-3/UHXb
Section 3: Bodenrand-3/UHXb
Section 3: Schale-Rand-3/UHXb
Section 4: Bodenrand-3/UHXb
Section 4: Schale-Rand-3/UHXb
Section 5: Bodenrand-3/UHXb
Section 5: Schale-Rand-3/UHXb
Section 6: Bodenrand-3/UHXb
Section 6: Schale-Rand-3/UHXb
Section 7: Bodenrand-3/UHXb
Section 7: Schale-Rand-3/UHXb
Section 8: Bodenrand-3/UHXb
Section 8: Schale-Rand-3/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]: 20 Pressure [bar]: 0
Thickness [mm]: 77,79 Outside diameter [mm]: 1028,7

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

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]: 371,11 Pressure [bar]: 0
Thickness [mm]: 15,75 Outside diameter [mm]: 15,75

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	181,3112

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					