Table of contents

Table of contents....1
1 E4.18.7 (D1) ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....2
2 E4.18.7 (D2) ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....8
3 E4.18.7 (D3) ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....14
4 E4.18.7 (O4) ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....20
5 E4.18.7 (O1) ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....26
6 E4.18.7 (O2) ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....32
7 E4.18.7 (O3) ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....38
8 E4.18.7 (D1) plastic ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....44
9 E4.18.7 (D2) plastic ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017....50
10 Comparison Form for equations....56
11 Comparison Form for equations....58
12 Comparison Form for equations....60
Appendix: Material documentation....62

Layout

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

1 E4.18.7 (D1)
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

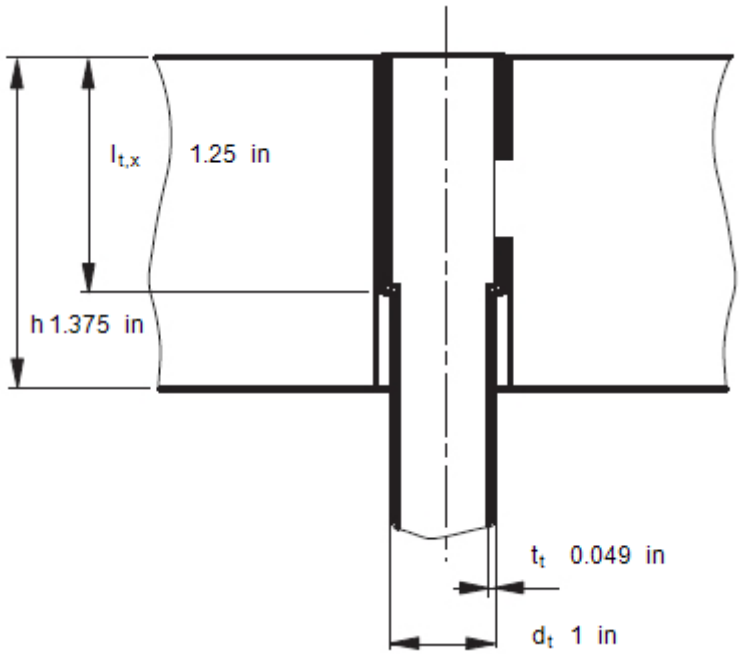
Configuration of the tubesheet (a, b, c, d)	Type	*a*		(a-d)
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	(1,2)
Internal operation pressure shell side		P_s	*325*	psi
Internal operation pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}	*325*	psi
Internal test pressure tube side		P_{tp}	*200*	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	*S30403-SA-240-304L-Class:-Size:*			
Tube material	*S30403-SA-249-TP304L-Class:-Size:*			
Shell material (Type abc)	*S30403-SA-240-304L-Class:-Size:*			
Channel material (Type a)	*K02700-SA-516-70-Class:-Size:*			

Operation	**Tubesheet**		**Tubes**		**Shell**		**Channel**	
Temperature	*400*	°F	*300*	°F	*400*	°F	*300*	°F
Thickness	*1.375*	in	*0.049*	in	*0.5625*	in	*0.375*	in
Outside diameter	*43.13*	in	*1*	in	*43.13*	in	*42.88*	in
Poiss.ratio	-		*0.3*		*0.3*		*0.3*	
Allow. c1	0	in	0	in	0	in	0	in
Corros. all. c_2	*0*	in	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature								
Strength op	15864	psi	14185	psi	15864	psi	20015	psi
Safety op.	1		1		1		1	
E-module	*2.64e+7*	psi	*2.7e+7*	psi	*2.64e+7*	psi	*2.83e+7*	psi
Therm.exp.	*9.462*	1E-6/°F	*9.217*	1E-6/°F	*9.462*	1E-6/°F	*6.885*	1E-6/°F
Yield str.	*17446*	psi	*19184*	psi	*17446*	psi	*33668*	psi
Limit temperature	896	°F	896	°F	896	°F	752	°F
All.stress	*15800*	psi	14200	psi	*15800*	psi	*20000*	psi
Pr.+sec.st	***47400***	psi			***47400***	psi	***67336***	psi
Properties for testing at 20°C								
Strength	22191	psi	22191	psi	22191	psi	33939	psi
Safety	1		1		1		1	
Yield str.	24656	psi	24656	psi	24656	psi	37710	psi
Tensile str.	70343	psi	70343	psi	70343	psi	70343	psi

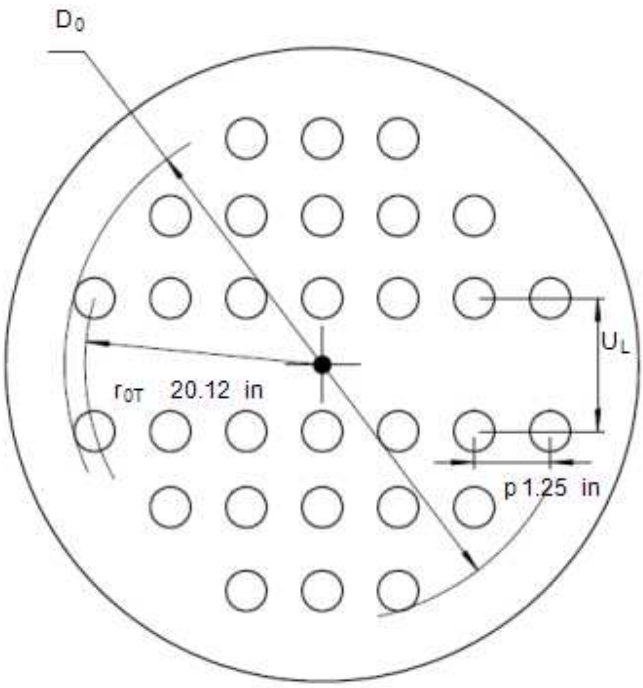
Additional specifications for the geometry and loading

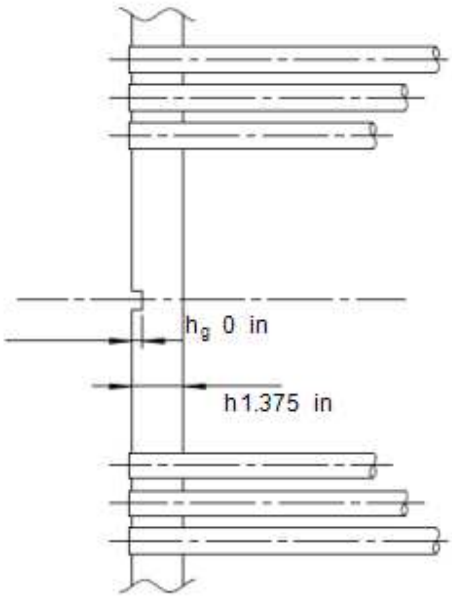
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*955*	



Expanded length of tube in tubesheet		$l_{t,x}$	*1.25*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*20.12*	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	*237.2*	in
Unsupported tube span for buckling	l	48	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	***48***	in
Bellows inside diameter at its convolution height	D_j	*40*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	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}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.802*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.65*	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15800	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9109**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2713**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5434**	
Type abc: Coefficients for shell pressure	δ_S	**0.09301**	mm^3/N
β_S **4.458** 1/ft k_S **319697** lbf	λ_S	**5.087e+7**	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **5.464** 1/ft k_C **124462** lbf	λ_C	**2.205e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8370275**	lbf/in
Tube axial rigidity	K_t	**16660**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5261**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3					E*	7265202	psi
Ratio of elasticity tubesheet							E*/E	0.2752	
effective Poisson's ratio tubesheet							v*	0.3402	
Parameter for table UHX-13.1							X_a	7.014	
Z_d	0.004332	Z_v	0.02064	Z_m	0.2068	Z_a	295.2	Z_w	0.02064

Step 4

Diameter ratio = A/D0						K	1.045
F	6.728		Φ	9.018		Q_1	-0.0586
Q_{z1}	3.779		Q_{z2}	10.32		U	20.65

UHX-13.5.5 Step 5, coefficients

γ(*)	0	in	ω_S	4.613	in²	ω_S*	-4.541	in²
ω_C	3.344	in²	ω_C*	-2.629	in²	γ_b	0	

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'	543.6	psi	P_γ	0	psi
P_W	0	psi	P_{rim}	-25.51	psi	P_e	-96.98	psi

UHX-13.5.7 Step 7

Q_2	183.5	lbf	Q_3	-0.0675		F_m	0.03375

Strength condition for the tubesheet bending stress, case 1

σ =	16289	psi	< 1.5 · σ_B =	1.5·	*15800*	psi	case 1-3	
			< S_{PS} =		***47400***	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau = 1.45e+11 psi < 0.8· σ_B = 12640 psi

Step 9: Shear stress Tau > 0.8*SigZul, tubesheet too thin

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

F_{tmin}	-0.2705		F_{tmax}	3.557	
x_{min}	2.907		x_{max}	7.014	
$\sigma_{T,1}$	-1290	psi	$\sigma_{T,2}$	2258	psi

σ_{tmax} =	2258	psi	≤ σ_T =	14200	psi	for calculation case 1-3
			≤2 · σ_T =	28400	psi	for calculation case 4-7

Tube weld force W_t = 330.6 lbf ≤ $W_{t,all}$ = 0 lbf

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

r_t	0.3367	in	F_t	142.6	C_t	1.472	F_s	166.7

$|\sigma_{tmin}|$ = | -1290 psi | ≤S_{tb} = 7460 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 = *0.5625* in : (calculation case)

$\sigma_{Sm} \le$ *1·* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **1830** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

|**1830** psi| < Min(**6749** psi , **43039** psi)

ASME external pressure chart HA-3 A = **0.00326**

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

$\sigma_{Sm} \le$ *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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **13998** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = **1830** psi | + | **-12168** psi | ≤ **23700** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **33899** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = **5567** psi | + | **28331** psi | ≤ **30000** psi

Minimum shell length with uniform thickness l_{Sm} **8.75** in

Minimum channel thickness with uniform thickness l_{Cm} **7.154** 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	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.83e+7** psi	**2.83e+7** 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 = **13998** psi ≤ ***47400*** 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 = **33899** psi ≤ ***67336*** psi $=S_{PSc}$

Geometric conditions:

valid

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

Strength violated for calculation case: 1 2

13.4(d) If: Tube sheet thickness= *1.375* 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
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1465898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2918\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186160\ \text{MPa}}{182023\ \text{MPa}} \cdot \frac{97.91\ \text{MPa}}{108.9\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.14\ \text{mm}}{23.14\ \text{mm}} = 0.2713$$

2 E4.18.7 (D2)
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

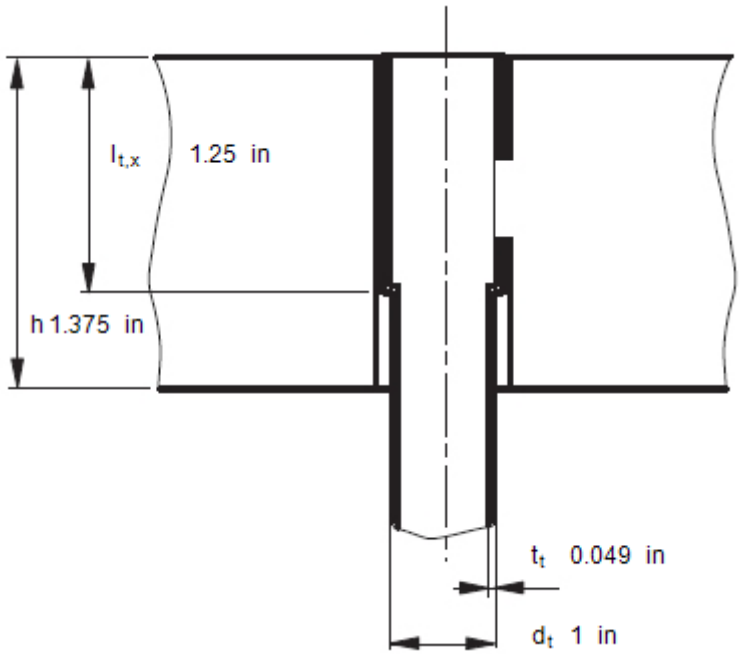
Configuration of the tubesheet (a, b, c, d)		Type	*a*	(a-d)
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	(1,2)
Internal operation pressure shell side		P_s	*325*	psi
Internal operation pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}	*325*	psi
Internal test pressure tube side		P_{tp}	*200*	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	*S30403-SA-240-304L-Class:-Size:*			
Tube material	*S30403-SA-249-TP304L-Class:-Size:*			
Shell material (Type abc)	*S30403-SA-240-304L-Class:-Size:*			
Channel material (Type a)	*K02700-SA-516-70-Class:-Size:*			

Operation	**Tubesheet**		**Tubes**		**Shell**		**Channel**	
Temperature	*400*	°F	*300*	°F	*400*	°F	*300*	°F
Thickness	*1.375*	in	*0.049*	in	*0.5625*	in	*0.375*	in
Outside diameter	*43.13*	in	*1*	in	*43.13*	in	*42.88*	in
Poiss.ratio	-		*0.3*		*0.3*		*0.3*	
Allow. c1	0	in	0	in	0	in	0	in
Corros. all. c_2	*0*	in	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature								
Strength op	15864	psi	14185	psi	15864	psi	20015	psi
Safety op.	1		1		1		1	
E-module	*2.64e+7*	psi	*2.699e+7*	psi	*2.64e+7*	psi	*2.829e+7*	psi
Therm.exp.	*9.462*	1E-6/°F	*9.217*	1E-6/°F	*9.462*	1E-6/°F	*6.885*	1E-6/°F
Yield str.	*17446*	psi	*19184*	psi	*17446*	psi	*33668*	psi
Limit temperature	896	°F	896	°F	896	°F	752	°F
All.stress	*15800*	psi	***14185***	psi	*15800*	psi	*20015*	psi
Pr.+sec.st	***47400***	psi			***47400***	psi	***67336***	psi
Properties for testing at 20°C								
Strength	22191	psi	22191	psi	22191	psi	33939	psi
Safety	1		1		1		1	
Yield str.	24656	psi	24656	psi	24656	psi	37710	psi
Tensile str.	70343	psi	70343	psi	70343	psi	70343	psi

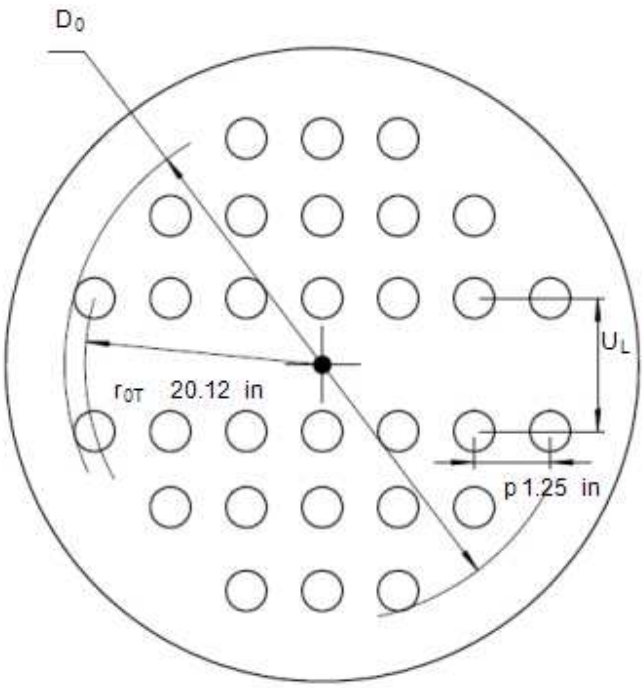
Additional specifications for the geometry and loading

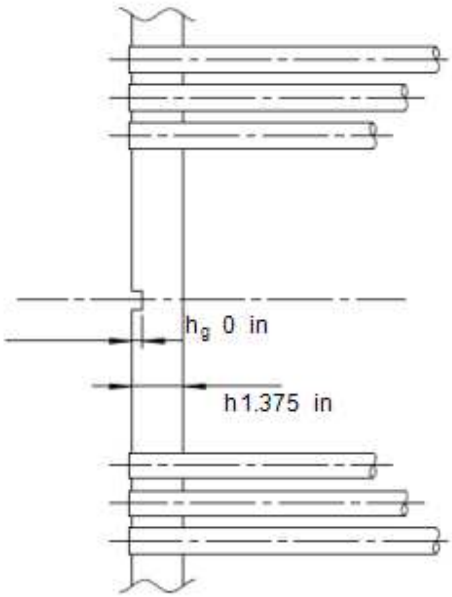
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*955*	



Expanded length of tube in tubesheet		$l_{t,x}$	*1.25*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*20.12*	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	*237.2*	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	*48*	in
Bellows inside diameter at its convolution height	D_j	*40*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	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}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.802*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.65*	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15800	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9109**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2713**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_aTUBE/a_0)^2$	x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_iTUBE/a_0)^2$	x_t	**0.5434**	
Type abc: Coefficients for shell pressure	δ_S	**0.09301**	mm^3/N
β_S **4.458** 1/ft k_S **319697** lbf	λ_S	**5.087e+7**	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **5.464** 1/ft k_C **124426** lbf	λ_C	**2.204e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8370275**	lbf/in
Tube axial rigidity	K_t	**16652**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5264**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3					E*	7265202	psi
Ratio of elasticity tubesheet							E*/E	0.2752	
effective Poisson's ratio tubesheet							v*	0.3402	
Parameter for table UHX-13.1							X_a	7.013	
Z_d	0.004334	Z_v	0.02065	Z_m	0.2068	Z_a	294.8	Z_w	0.02065

Step 4

Diameter ratio = A/D0						K	1.045
F	6.728		Φ	9.017		Q_1	-0.05861
Q_{z1}	3.778		Q_{z2}	10.32		U	20.64

UHX-13.5.5 Step 5, coefficients

γ(*)	0	in	ω_S	4.613	in²	ω_S*	-4.541	in²
ω_C	3.344	in²	ω_C*	-2.629	in²	γ_b	0	

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'	613.4	psi	P_t'	0	psi	P_γ	0	psi
P_W	0	psi	P_{rim}	71.61	psi	P_e	116.8	psi

UHX-13.5.7 Step 7

Q_2	-515.3	lbf	Q_3	-0.07936		F_m	0.03968

Strength condition for the tubesheet bending stress, case 2

σ =	23055	psi	< 1.5 · σ_B	=	1.5·	*15800*	psi	case 1-3
			< S_{PS}	=		***47400***	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau =	1.45e+11	psi	< 0.8· σ_B	=	12640	psi

Step 9: Shear stress Tau > 0.8*SigZul, tubesheet too thin

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

F_{tmin}	-0.2431		F_{tmax}	3.26	
x_{min}	2.721		x_{max}	7.013	
$\sigma_{T,1}$	1634	psi	$\sigma_{T,2}$	-2275	psi

σ_{tmax} =	1634	psi	≤ σ_T	=	***14185***	psi	for calculation case 1-3
			≤2 · σ_T	=	28369	psi	for calculation case 4-7

Tube weld force W_t = 239.3 lbf ≤ $W_{t,all}$ = 0 lbf

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

r_t	0.3367	in	F_t	142.6		C_t	1.62	F_s	166.6

$\lvert\sigma_{tmin}\rvert$ =	-2275	psi	≤S_{tb} =	6776	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 = *0.5625* in : (calculation case)

$\sigma_{Sm} \le$ *1·* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **2287** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

2287 psi < Min(**6749** psi , **43039** psi)

ASME external pressure chart HA-3 A = **0.00326**

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

$\sigma_{Sm} \le$ *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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **30052** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = **2287** psi | + | **27765** psi | ≤ **23700** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **8504** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = **0** psi | + | **-8504** psi | ≤ **30023** psi

Minimum shell length with uniform thickness l_{Sm} **8.75** in

Minimum channel thickness with uniform thickness l_{Cm} **7.154** 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	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.829e+7** psi	**2.829e+7** 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 = **30052** psi ≤ ***47400*** 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 = **8504** psi ≤ ***67336*** psi $= S_{PSc}$

Geometric conditions:

valid

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

13.4(d) If: Tube sheet thickness= *1.375* 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
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1465898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2916\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186067\ \text{MPa}}{182023\ \text{MPa}} \cdot \frac{97.8\ \text{MPa}}{108.9\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.14\ \text{mm}}{23.14\ \text{mm}} = 0.2713$$

3 E4.18.7 (D3)
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

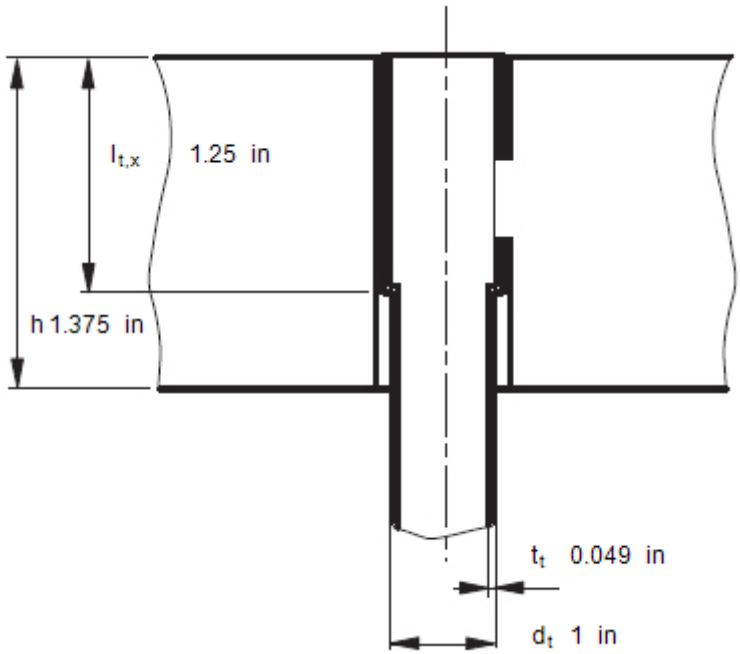
Configuration of the tubesheet (a, b, c, d)		Type	*a*	(a-d)
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	(1,2)
Internal operation pressure shell side		P_s	*325*	psi
Internal operation pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}	*325*	psi
Internal test pressure tube side		P_{tp}	*200*	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	*S30403-SA-240-304L-Class:-Size:*			
Tube material	*S30403-SA-249-TP304L-Class:-Size:*			
Shell material (Type abc)	*S30403-SA-240-304L-Class:-Size:*			
Channel material (Type a)	*K02700-SA-516-70-Class:-Size:*			

Operation	**Tubesheet**		**Tubes**		**Shell**		**Channel**	
Temperature	*400*	°F	*300*	°F	*400*	°F	*300*	°F
Thickness	*1.375*	in	*0.049*	in	*0.5625*	in	*0.375*	in
Outside diameter	*43.13*	in	*1*	in	*43.13*	in	*42.88*	in
Poiss.ratio	-		*0.3*		*0.3*		*0.3*	
Allow. c1	0	in	0	in	0	in	0	in
Corros. all. c_2	*0*	in	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature								
Strength op	15864	psi	14185	psi	15864	psi	20015	psi
Safety op.	1		1		1		1	
E-module	*2.64e+7*	psi	*2.699e+7*	psi	*2.64e+7*	psi	*2.829e+7*	psi
Therm.exp.	*9.462*	1E-6/°F	*9.217*	1E-6/°F	*9.462*	1E-6/°F	*6.885*	1E-6/°F
Yield str.	*17446*	psi	*19184*	psi	*17446*	psi	*33668*	psi
Limit temperature	896	°F	896	°F	896	°F	752	°F
All.stress	*15800*	psi	***14185***	psi	*15800*	psi	*20015*	psi
Pr.+sec.st	***47400***	psi			***47400***	psi	***67336***	psi
Properties for testing at 20°C								
Strength	22191	psi	22191	psi	22191	psi	33939	psi
Safety	1		1		1		1	
Yield str.	24656	psi	24656	psi	24656	psi	37710	psi
Tensile str.	70343	psi	70343	psi	70343	psi	70343	psi

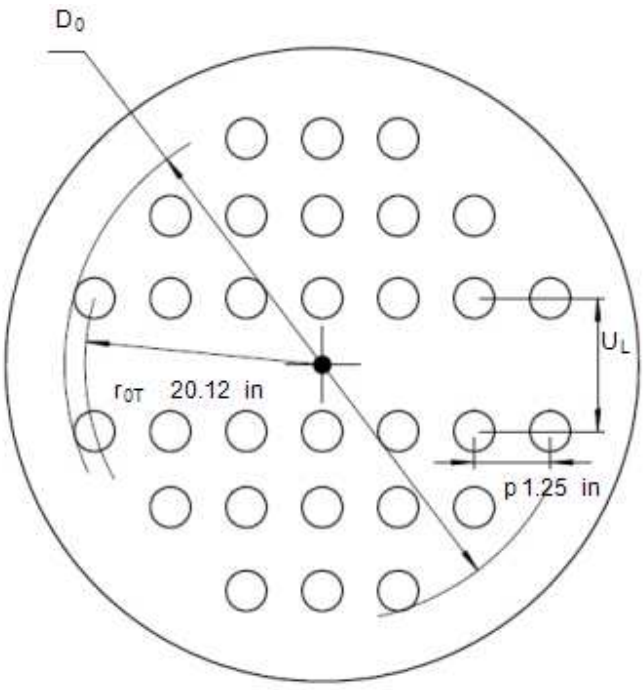
Additional specifications for the geometry and loading

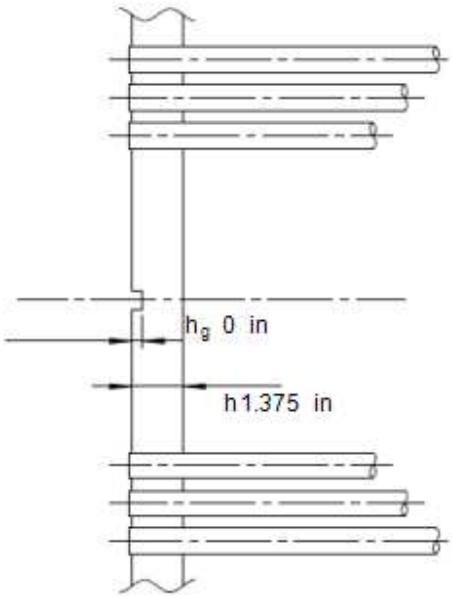
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*955*	



Expanded length of tube in tubesheet		$l_{t,x}$	*1.25*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*20.12*	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	*237.2*	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	*48*	in
Bellows inside diameter at its convolution height	D_j	*40*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	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}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.802*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.65*	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15800	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9109**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2713**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5434**	
Type abc: Coefficients for shell pressure	δ_S	**0.09301**	mm^3/N
β_S **4.458** 1/ft k_S **319697** lbf	λ_S	**5.087e+7**	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **5.464** 1/ft k_C **124426** lbf	λ_C	**2.204e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8370275**	lbf/in
Tube axial rigidity	K_t	**16652**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5264**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3					E*	7265202	psi
Ratio of elasticity tubesheet							E*/E	0.2752	
effective Poisson's ratio tubesheet							v*	0.3402	
Parameter for table UHX-13.1							X_a	7.013	
Z_d	0.004334	Z_v	0.02065	Z_m	0.2068	Z_a	294.8	Z_w	0.02065

Step 4

Diameter ratio = A/D0								K	1.045
F	6.728			Φ	9.017			Q_1	-0.05861
Q_{z1}	3.778			Q_{z2}	10.32			U	20.64

UHX-13.5.5 Step 5, coefficients

γ(*)	0	in		ω_S	4.613	in²		ω_S*	-4.541	in²
ω_C	3.344	in²		ω_C*	-2.629	in²		γ_b	0	

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'	613.4	psi		P_t'	543.4	psi		P_γ	0	psi
P_W	0	psi		P_{rim}	46.1	psi		P_e	19.78	psi

UHX-13.5.7 Step 7

Q_2	-331.7	lbf		Q_3	-0.1375			F_m	0.06873	
Strength condition for the tubesheet bending stress, case							3			
σ =	6766	psi	< 1.5 · σ_B	=	1.5·	*15800*	psi	case 1-3		
			< S_{PS}	=		***47400***	psi	case 4-7		

Step 8

Strength condition for the tubesheet shear stress:

Tau =	0	psi	< 0.8· σ_B	=	12640	psi

Strength condition of step 7-8 are satisfied.

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

F_{tmin}	-0.1907			F_{tmax}	2.126				
x_{min}	1.599			x_{max}	6.492				
$\sigma_{T,1}$	360.3	psi		$\sigma_{T,2}$	-77.71	psi			

σ_{tmax} =	360.3	psi	≤ σ_T	=	***14185***	psi	for calculation case 1-3	
			≤2 · σ_T	=	28369	psi	for calculation case 4-7	

Tube weld force W_t = 52.75 lbf ≤ $W_{t,all}$ = 0 lbf

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

r_t	0.3367	in	F_t	142.6		C_t	2	F_s	166.6

$\lvert\sigma_{tmin}\rvert$ =	-77.71	psi	≤S_{tb} =	5489	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 = *0.5625* in : (calculation case)

$\sigma_{Sm} \le$ *1*· *15800* psi = $E_{sw}\cdot\sigma_{allS}$ (1-3)

σ_{Sm} = **4118** psi ≤2· *15800* psi = $2\cdot\sigma_{allS}$ (4-7)

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

4118 psi < Min(**6749** psi , **43039** psi)

ASME external pressure chart HA-3 A = **0.00326**

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

$\sigma_{Sm} \le$ *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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **19714** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = **4118** psi | + | **15596** psi | ≤ **23700** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **25393** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = **5567** psi | + | **19826** psi | ≤ **30023** psi

Minimum shell length with uniform thickness l_{Sm} **8.75** in

Minimum channel thickness with uniform thickness l_{Cm} **7.154** 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	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.829e+7** psi	**2.829e+7** 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 = **19714** psi ≤ ***47400*** 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 = **25393** psi ≤ ***67336*** psi =S_{PSc}

Geometric conditions:

valid

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

13.4(d) If: Tube sheet thickness= *1.375* 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
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1465898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2916\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186067\ \text{MPa}}{182023\ \text{MPa}} \cdot \frac{97.8\ \text{MPa}}{108.9\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.14\ \text{mm}}{23.14\ \text{mm}} = 0.2713$$

4 E4.18.7 (O4)
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

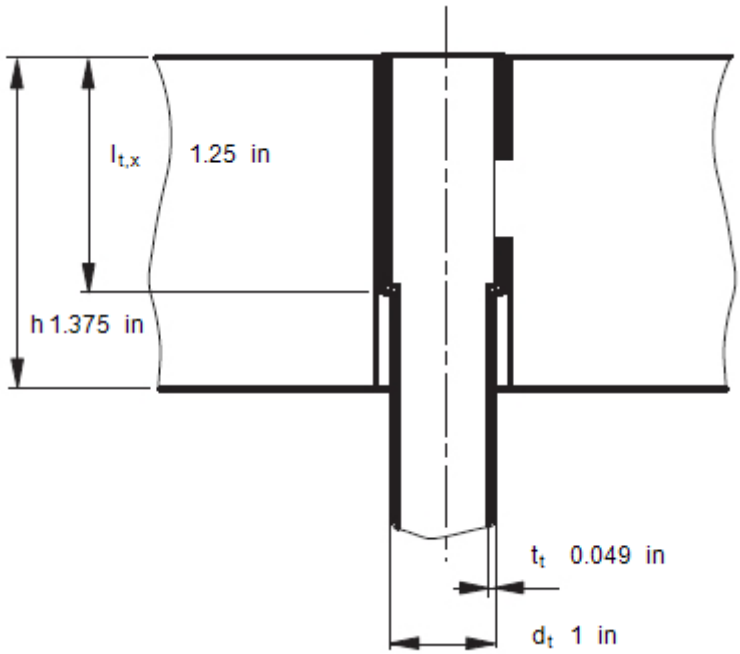
Configuration of the tubesheet (a, b, c, d)	Type	*a*	(a-d)
Tubesheet integral with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	(1,2)
Internal operation pressure shell side	P_s	*325*	psi
Internal operation pressure tube side	P_t	*200*	psi
Internal test pressure shell side	P_{sp}		psi
Internal test pressure tube side	P_{tp}	*200*	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	*S30403-SA-240-304L-Class:-Size:*		
Tube material	*S30403-SA-249-TP304L-Class:-Size:*		
Shell material (Type abc)	*S30403-SA-240-304L-Class:-Size:*		
Channel material (Type a)	*K02700-SA-516-70-Class:-Size:*		

Operation	**Tubesheet**		**Tubes**		**Shell**		**Channel**	
Temperature	*400*	°F	*300*	°F	*400*	°F	*300*	°F
Thickness	*1.375*	in	*0.049*	in	*0.5625*	in	*0.375*	in
Outside diameter	*43.13*	in	*1*	in	*43.13*	in	*42.88*	in
Poiss.ratio	-		*0.3*		*0.3*		*0.3*	
Allow. c1	0	in	0	in	0	in	0	in
Corros. all. c_2	*0*	in	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature								
Strength op	15864	psi	14185	psi	15864	psi	20015	psi
Safety op.	1		1		1		1	
E-module	*2.64e+7*	psi	*2.699e+7*	psi	*2.64e+7*	psi	*2.829e+7*	psi
Therm.exp.	*9.462*	1E-6/°F	*9.217*	1E-6/°F	*9.462*	1E-6/°F	*6.885*	1E-6/°F
Yield str.	*17446*	psi	*19184*	psi	*17446*	psi	*33668*	psi
Limit temperature	896	°F	896	°F	896	°F	752	°F
All.stress	*15800*	psi	***14185***	psi	*15800*	psi	*20015*	psi
Pr.+sec.st	***47400***	psi			***47400***	psi	***67336***	psi
Properties for testing at 20°C								
Strength	22191	psi	22191	psi	22191	psi	33939	psi
Safety	1		1		1		1	
Yield str.	24656	psi	24656	psi	24656	psi	37710	psi
Tensile str.	70343	psi	70343	psi	70343	psi	70343	psi

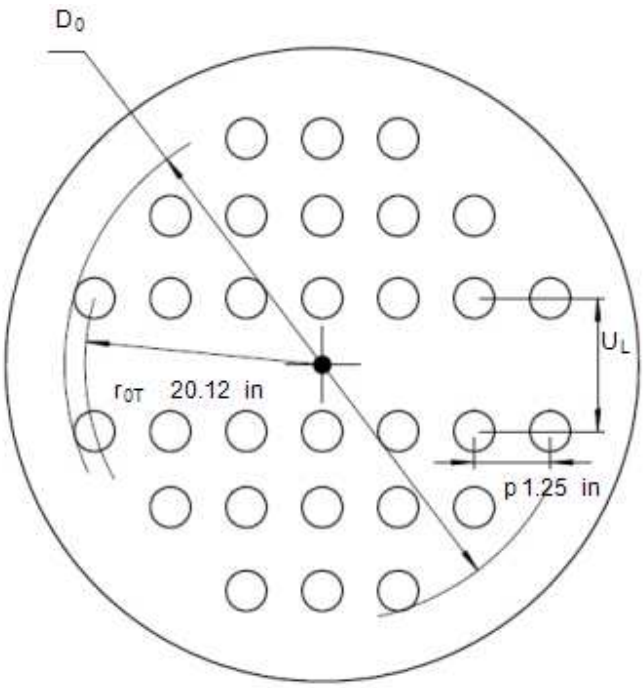
Additional specifications for the geometry and loading

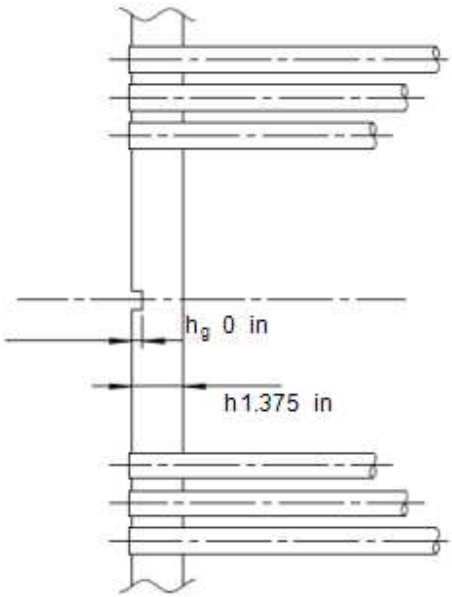
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*955*	



Expanded length of tube in tubesheet		$l_{t,x}$	*1.25*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*20.12*	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	*237.2*	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	*48*	in
Bellows inside diameter at its convolution height	D_j	*40*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	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}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.802*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.65*	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15800	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9109**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2713**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5434**	
Type abc: Coefficients for shell pressure	δ_S	**0.09301**	mm^3/N
β_S **4.458** 1/ft k_S **319697** lbf	λ_S	**5.087e+7**	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **5.464** 1/ft k_C **124426** lbf	λ_C	**2.204e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8370275**	lbf/in
Tube axial rigidity	K_t	**16652**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5264**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3					E*	7265202	psi
Ratio of elasticity tubesheet							E*/E	0.2752	
effective Poisson's ratio tubesheet							v*	0.3402	
Parameter for table UHX-13.1							X_a	7.013	
Z_d	0.004334	Z_v	0.02065	Z_m	0.2068	Z_a	294.8	Z_w	0.02065

Step 4

Diameter ratio = A/D0								K	1.045
F	6.728			Φ	9.017			Q_1	-0.05861
Q_{z1}	3.778			Q_{z2}	10.32			U	20.64

UHX-13.5.5 Step 5, coefficients

γ(*)	-0.08098	in		ω_S	4.613	in²		ω_S*	-4.541	in²
ω_C	3.344	in²		ω_C*	-2.629	in²		γ_b	0	

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	-963.6	psi
P_W	0	psi		P_{rim}	0	psi		P_e	-164.2	psi

UHX-13.5.7 Step 7

Q_2	0	lbf		Q_3	-0.05861			F_m	0.02931	
Strength condition for the tubesheet bending stress, case							4			
σ =	23953	psi	< 1.5 · σ_B	=	1.5·	*15800*	psi	case 1-3		
			< S_{PS}	=		***47400***	psi	case 4-7		

Step 8

Strength condition for the tubesheet shear stress:

Tau = **1.45e+11** psi < 0.8· σ_B = **12640** psi

Step 9: Shear stress Tau > 0.8*SigZul, tubesheet too thin

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

F_{tmin}	-0.2949		F_{tmax}	3.778	
x_{min}	3.03		x_{max}	7.013	
$\sigma_{T,1}$	-463	psi	$\sigma_{T,2}$	5932	psi

σ_{tmax} =	5932	psi	≤ σ_T =	***14185***	psi	for calculation case 1-3
			≤2 · σ_T =	28369	psi	for calculation case 4-7

Tube weld force W_t = **868.4** lbf ≤ $W_{t,all}$ = 0 lbf

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

r_t	0.3367	in	F_t	142.6	C_t	1.361	F_s	166.6

$|\sigma_{tmin}|$ = | -463 psi | ≤S_{tb} = 8067 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 = *0.5625* in : (calculation case)

$\sigma_{Sm} \le$ *1·* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **-2918** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **-2918** psi | < Min(**6749** psi , **43039** psi)

ASME external pressure chart HA-3 A = **0.00326**

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

$\sigma_{Sm} \le$ *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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **29196** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = **-2918** psi | + | **-26278** psi | ≤ **47400** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **24068** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = **0** psi | + | **24068** psi | ≤ **67336** psi

Minimum shell length with uniform thickness l_{Sm} **8.75** in

Minimum channel thickness with uniform thickness l_{Cm} **7.154** 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	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.829e+7** psi	**2.829e+7** 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 = **29196** psi ≤ ***47400*** 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 = **24068** psi ≤ ***67336*** psi $=S_{PSc}$

Geometric conditions:

valid

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

13.4(d) If: Tube sheet thickness= *1.375* 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
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1465898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2916\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186067\ \text{MPa}}{182023\ \text{MPa}} \cdot \frac{97.8\ \text{MPa}}{108.9\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.14\ \text{mm}}{23.14\ \text{mm}} = 0.2713$$

5 E4.18.7 (O1)
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

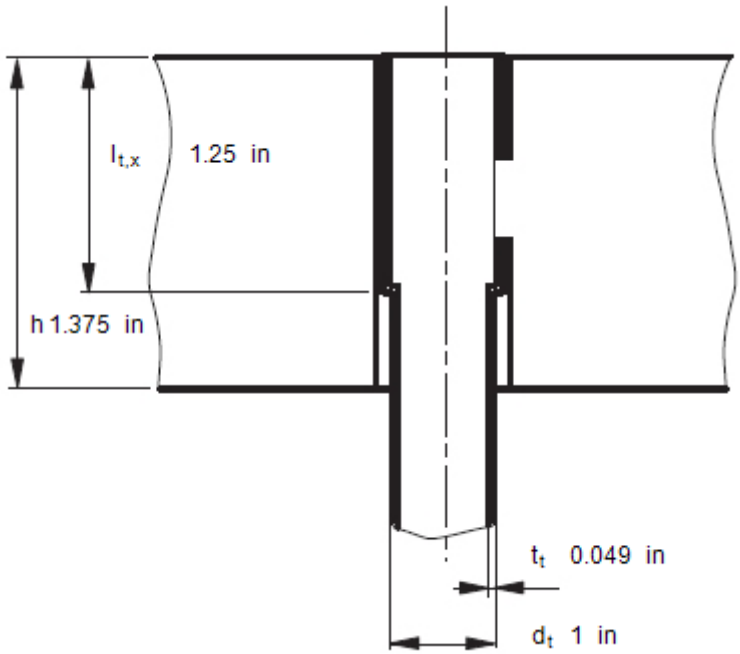
Configuration of the tubesheet (a, b, c, d)		Type	*a*	(a-d)
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	(1,2)
Internal operation pressure shell side		P_s	*325*	psi
Internal operation pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}	*325*	psi
Internal test pressure tube side		P_{tp}	*200*	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	*S30403-SA-240-304L-Class:-Size:*			
Tube material	*S30403-SA-249-TP304L-Class:-Size:*			
Shell material (Type abc)	*S30403-SA-240-304L-Class:-Size:*			
Channel material (Type a)	*K02700-SA-516-70-Class:-Size:*			

Operation	**Tubesheet**		**Tubes**		**Shell**		**Channel**	
Temperature	*400*	°F	*300*	°F	*400*	°F	*300*	°F
Thickness	*1.375*	in	*0.049*	in	*0.5625*	in	*0.375*	in
Outside diameter	*43.13*	in	*1*	in	*43.13*	in	*42.88*	in
Poiss.ratio	-		*0.3*		*0.3*		*0.3*	
Allow. c1	0	in	0	in	0	in	0	in
Corros. all. c_2	*0*	in	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature								
Strength op	15864	psi	14185	psi	15864	psi	20015	psi
Safety op.	1		1		1		1	
E-module	*2.64e+7*	psi	*2.699e+7*	psi	*2.64e+7*	psi	*2.829e+7*	psi
Therm.exp.	*9.462*	1E-6/°F	*9.217*	1E-6/°F	*9.462*	1E-6/°F	*6.885*	1E-6/°F
Yield str.	*17446*	psi	*19184*	psi	*17446*	psi	*33668*	psi
Limit temperature	896	°F	896	°F	896	°F	752	°F
All.stress	*15800*	psi	***14185***	psi	*15800*	psi	*20015*	psi
Pr.+sec.st	***47400***	psi			***47400***	psi	***67336***	psi
Properties for testing at 20°C								
Strength	22191	psi	22191	psi	22191	psi	33939	psi
Safety	1		1		1		1	
Yield str.	24656	psi	24656	psi	24656	psi	37710	psi
Tensile str.	70343	psi	70343	psi	70343	psi	70343	psi

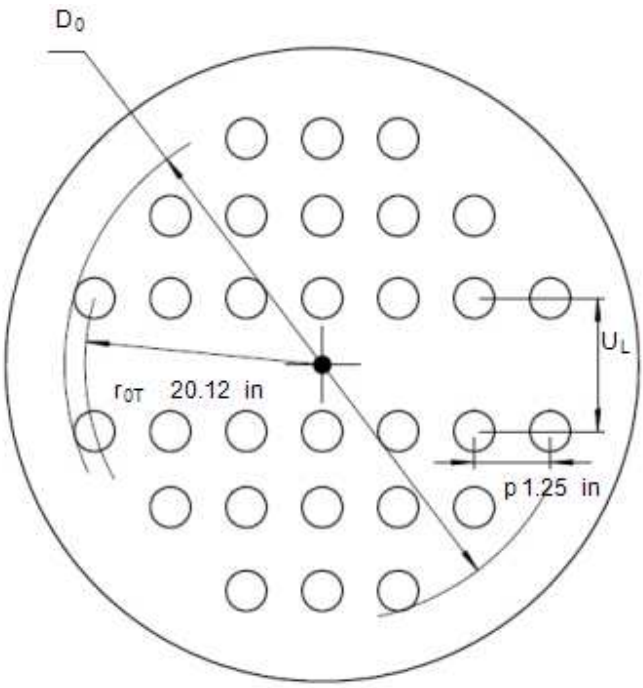
Additional specifications for the geometry and loading

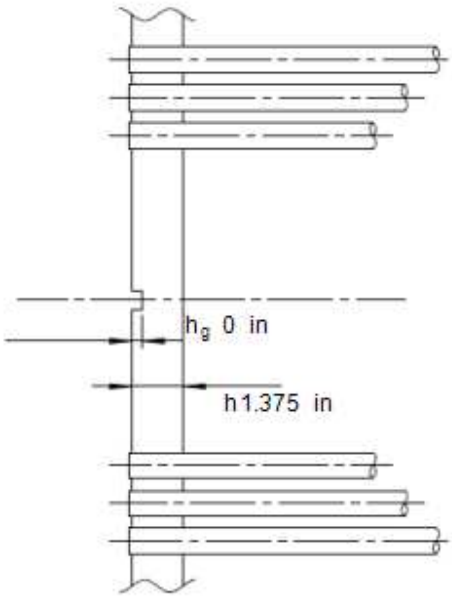
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*955*	



Expanded length of tube in tubesheet		$l_{t,x}$	*1.25*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*20.12*	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	*237.2*	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	*48*	in
Bellows inside diameter at its convolution height	D_j	*40*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	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}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.802*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.65*	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5							
Tube material mod. of elast. at tubesheet temperature T					E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T					K_{tT}	15800	psi
Tube material allowable stress safety at T					S_{fT}	1	-
Basic ligament efficiency for shear					μ	**0.2**	
Effective tube hole diameter					d*	**0.9109**	in
Effective pitch					p*	**1.25**	in
Effective ligament efficiency for shear					μ*	**0.2713**	
Effective depth of pass partition groove					h_g'	**0**	in
Equivalent radius of outer tube limit circle					a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)					a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)					a_s	**21**	in
Ratio = ac/a0					ρ_C	**1.021**	
Ratio = as/a0					ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$					x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$					x_t	**0.5434**	
Type abc: Coefficients for shell pressure					δ_S	**0.09301**	mm^3/N
β_S	**4.458**	1/ft	k_S	**319697** lbf	λ_S	**5.087e+7**	psi
Type a: Coefficients for channel pressure					δ_c	**0.1309**	mm^3/N
β_C	**5.464**	1/ft	k_C	**124426** lbf	λ_C	**2.204e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8370275**	lbf/in
Tube axial rigidity	K_t	**16652**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5264**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3					E*	7265202	psi
Ratio of elasticity tubesheet							E*/E	0.2752	
effective Poisson's ratio tubesheet							v*	0.3402	
Parameter for table UHX-13.1							X_a	7.013	
Z_d	0.004334	Z_v	0.02065	Z_m	0.2068	Z_a	294.8	Z_w	0.02065

Step 4

Diameter ratio = A/D0								K	1.045
F	6.728			Φ	9.017			Q_1	-0.05861
Q_{z1}	3.778			Q_{z2}	10.32			U	20.64

UHX-13.5.5 Step 5, coefficients

γ(*)	-0.08098	in		ω_S	4.613	in²		ω_S*	-4.541	in²
ω_C	3.344	in²		ω_C*	-2.629	in²		γ_b	0	

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'	543.4	psi		P_γ	-963.6	psi
P_W	0	psi		P_{rim}	-25.51	psi		P_e	-261.2	psi

UHX-13.5.7 Step 7

Q_2	183.5	lbf		Q_3	-0.06192			F_m	0.03096

Strength condition for the tubesheet bending stress, case 5

σ =	40242	psi	< 1.5 · σ_B =	1.5·	*15800*	psi		case 1-3
			< S_{PS} =		***47400***	psi		case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau =	1.45e+11	psi	< 0.8· σ_B =		12640	psi

Step 9: Shear stress Tau > 0.8*SigZul, tubesheet too thin

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

F_{tmin}	-0.2855		F_{tmax}	3.696	
x_{min}	2.985		x_{max}	7.013	
$\sigma_{T,1}$	-1752	psi	$\sigma_{T,2}$	8189	psi

σ_{tmax} =	8189	psi	≤ σ_T =	***14185***	psi	for calculation case 1-3
			≤2 · σ_T =	28369	psi	for calculation case 4-7

Tube weld force W_t = 1199 lbf ≤ $W_{t,all}$ = 0 lbf
(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	0.3367	in	F_t	142.6	C_t	1.402	F_s	166.6

$\lvert\sigma_{tmin}\rvert$ =	-1752	psi	$\lvert$ ≤S_{tb} =	7829	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 = *0.5625* in : (calculation case)

$\sigma_{Sm} \le$ *1·* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **-1087** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **-1087** psi | < Min(**6749** psi , **43039** psi)

ASME external pressure chart HA-3 A = **0.00326**

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

$\sigma_{Sm} \le$ *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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}| =$ **39534** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = **-1087** psi | + | **-38447** psi | ≤ **47400** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}| =$ **57965** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = **5567** psi | + | **52398** psi | ≤ **67336** psi

Minimum shell length with uniform thickness l_{Sm} **8.75** in

Minimum channel thickness with uniform thickness l_{Cm} **7.154** 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	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.829e+7** psi	**2.829e+7** 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 = **39534** psi ≤ ***47400*** 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 = **57965** psi ≤ ***67336*** psi $=S_{PSc}$

Geometric conditions:

valid

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

13.4(d) If: Tube sheet thickness= *1.375* 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
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1465898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2916\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186067\ \text{MPa}}{182023\ \text{MPa}} \cdot \frac{97.8\ \text{MPa}}{108.9\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.14\ \text{mm}}{23.14\ \text{mm}} = 0.2713$$

6 E4.18.7 (O2)
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

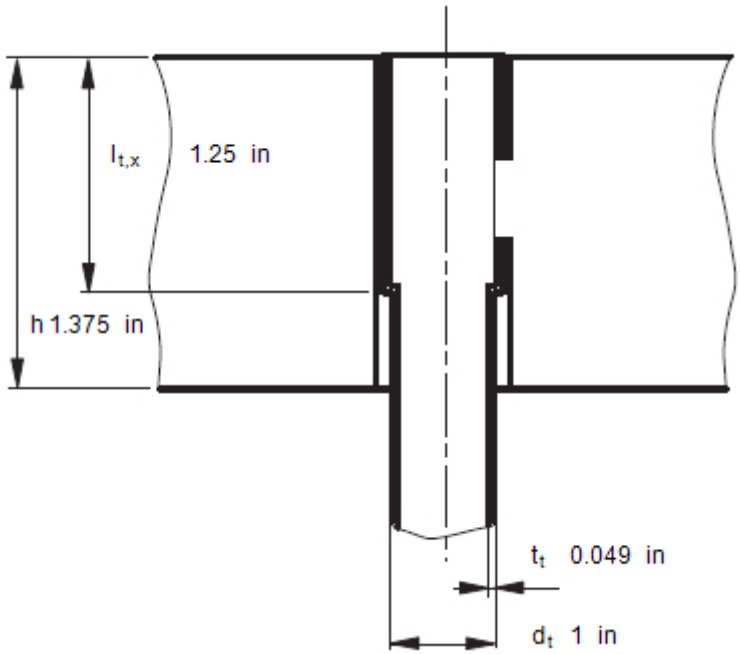
Configuration of the tubesheet (a, b, c, d)	Type	*a*	(a-d)
Tubesheet integral with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	(1,2)
Internal operation pressure shell side	P_s	*325*	psi
Internal operation pressure tube side	P_t	*200*	psi
Internal test pressure shell side	P_{sp}	*325*	psi
Internal test pressure tube side	P_{tp}	*200*	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	*S30403-SA-240-304L-Class:-Size:*		
Tube material	*S30403-SA-249-TP304L-Class:-Size:*		
Shell material (Type abc)	*S30403-SA-240-304L-Class:-Size:*		
Channel material (Type a)	*K02700-SA-516-70-Class:-Size:*		

Operation	**Tubesheet**		**Tubes**		**Shell**		**Channel**	
Temperature	*400*	°F	*300*	°F	*400*	°F	*300*	°F
Thickness	*1.375*	in	*0.049*	in	*0.5625*	in	*0.375*	in
Outside diameter	*43.13*	in	*1*	in	*43.13*	in	*42.88*	in
Poiss.ratio	-		*0.3*		*0.3*		*0.3*	
Allow. c1	0	in	0	in	0	in	0	in
Corros. all. c_2	*0*	in	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature								
Strength op	15864	psi	14185	psi	15864	psi	20015	psi
Safety op.	1		1		1		1	
E-module	*2.64e+7*	psi	*2.699e+7*	psi	*2.64e+7*	psi	*2.829e+7*	psi
Therm.exp.	*9.462*	1E-6/°F	*9.217*	1E-6/°F	*9.462*	1E-6/°F	*6.885*	1E-6/°F
Yield str.	*17446*	psi	*19184*	psi	*17446*	psi	*33668*	psi
Limit temperature	896	°F	896	°F	896	°F	752	°F
All.stress	*15800*	psi	***14185***	psi	*15800*	psi	*20015*	psi
Pr.+sec.st	***47400***	psi			***47400***	psi	***67336***	psi
Properties for testing at 20°C								
Strength	22191	psi	22191	psi	22191	psi	33939	psi
Safety	1		1		1		1	
Yield str.	24656	psi	24656	psi	24656	psi	37710	psi
Tensile str.	70343	psi	70343	psi	70343	psi	70343	psi

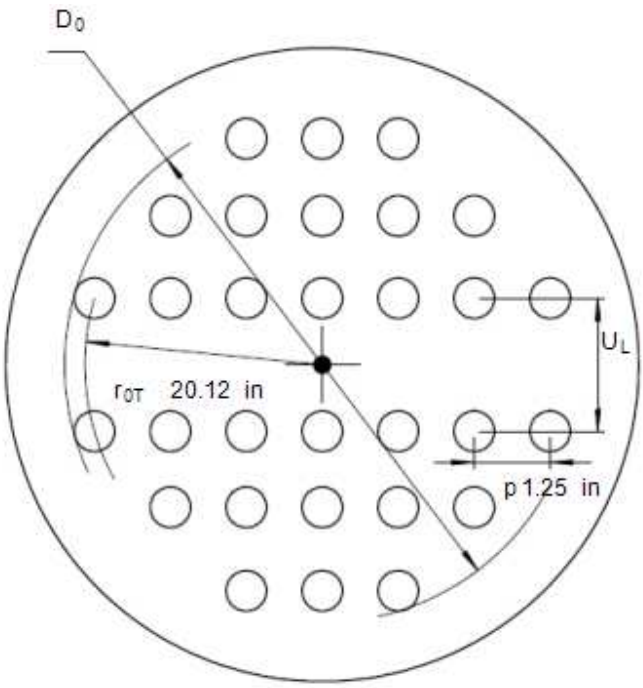
Additional specifications for the geometry and loading

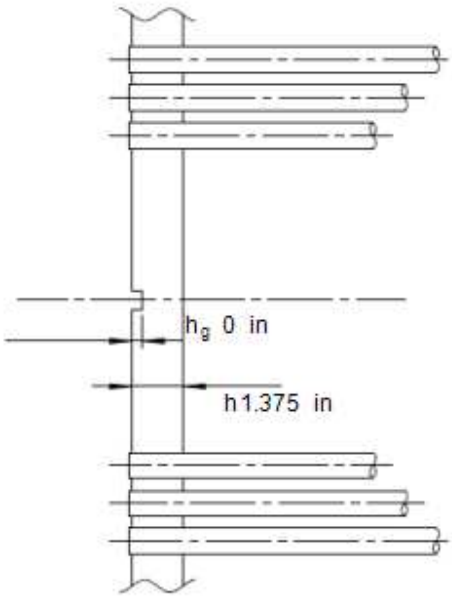
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*955*	



Expanded length of tube in tubesheet		$l_{t,x}$	*1.25*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*20.12*	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	*237.2*	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	*48*	in
Bellows inside diameter at its convolution height	D_j	*40*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	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}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.802*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.65*	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15800	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9109**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2713**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5434**	
Type abc: Coefficients for shell pressure	δ_S	**0.09301**	mm^3/N
β_S **4.458** 1/ft k_S **319697** lbf	λ_S	**5.087e+7**	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **5.464** 1/ft k_C **124426** lbf	λ_C	**2.204e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8370275**	lbf/in
Tube axial rigidity	K_t	**16652**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5264**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3					E^*	**7265202**	psi
Ratio of elasticity tubesheet							E^*/E	**0.2752**	
effective Poisson's ratio tubesheet							v^*	**0.3402**	
Parameter for table UHX-13.1							X_a	**7.013**	
Z_d	**0.004334**	Z_v	**0.02065**	Z_m	**0.2068**	Z_a	**294.8**	Z_w	**0.02065**

Step 4

Diameter ratio = A/D0						K	**1.045**
F	**6.728**		Φ	**9.017**		Q_1	**-0.05861**
Q_{z1}	**3.778**		Q_{z2}	**10.32**		U	**20.64**

UHX-13.5.5 Step 5, coefficients

γ(*)	**-0.08098**	in	ω_S	**4.613**	in²	ω_S^*	**-4.541**	in²
ω_C	**3.344**	in²	ω_C^*	**-2.629**	in²	γ_b	**0**	

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'	**613.4**	psi	P_t'	**0**	psi	P_γ	**-963.6**	psi
P_W	**0**	psi	P_{rim}	**71.61**	psi	P_e	**-47.48**	psi

UHX-13.5.7 Step 7

Q_2	**-515.3**	lbf	Q_3	**-7.6e-3**		F_m	**0.03208**

Strength condition for the tubesheet bending stress, case 6

σ =	**7580**	psi	$< 1.5 \cdot \sigma_B$ =	1.5·	*15800*	psi	case 1-3	
			$< S_{PS}$ =		***47400***	psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

Tau =	**0**	psi	$< 0.8 \cdot \sigma_B$ =	**12640**	psi

Strength condition of step 7-8 are satisfied.

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

F_{tmin}	**-0.4896**		F_{tmax}	**5.053**	
x_{min}	**3.574**		x_{max}	**7.013**	
$\sigma_{T,1}$	**1141**	psi	$\sigma_{T,2}$	**3657**	psi

σ_{tmax} =	**3657**	psi	$\leq \sigma_T$ =	***14185***	psi	for calculation case 1-3	
			$\leq 2 \cdot \sigma_T$ =	**28369**	psi	for calculation case 4-7	

Tube weld force W_t = **535.3** lbf $\leq W_{t,all}$ = 0 lbf

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

r_t	**0.3367**	in	F_t	**142.6**		C_t	**1.25**	F_s	**166.6**

$|\sigma_{tmin}|$ = | **1141** psi | $\leq S_{tb}$ = **8782** 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 = *0.5625* in : (calculation case)

$\sigma_{Sm} \le$ *1·* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **-630.3** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **-630.3** psi | < Min(**6749** psi , **43039** psi)

ASME external pressure chart HA-3 A = **0.00326**

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

$\sigma_{Sm} \le$ *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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}| =$ **2117** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

$\sigma_S =$ **-630.3** psi | + | **1487** psi | ≤ **47400** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}| =$ **15565** psi ≤1.5 · σ_{allC} or S_{PSc}

$\sigma_C =$ **0** psi | + | **15565** psi | ≤ **67336** psi

Minimum shell length with uniform thickness l_{Sm} **8.75** in

Minimum channel thickness with uniform thickness l_{Cm} **7.154** 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	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.829e+7** psi	**2.829e+7** 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 = **2117** psi ≤ ***47400*** 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 = **15565** psi ≤ ***67336*** psi $=S_{PSc}$

Geometric conditions:

valid

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

13.4(d) If: Tube sheet thickness= *1.375* 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
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1465898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2916\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186067\ \text{MPa}}{182023\ \text{MPa}} \cdot \frac{97.8\ \text{MPa}}{108.9\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.14\ \text{mm}}{23.14\ \text{mm}} = 0.2713$$

7 E4.18.7 (O3)
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

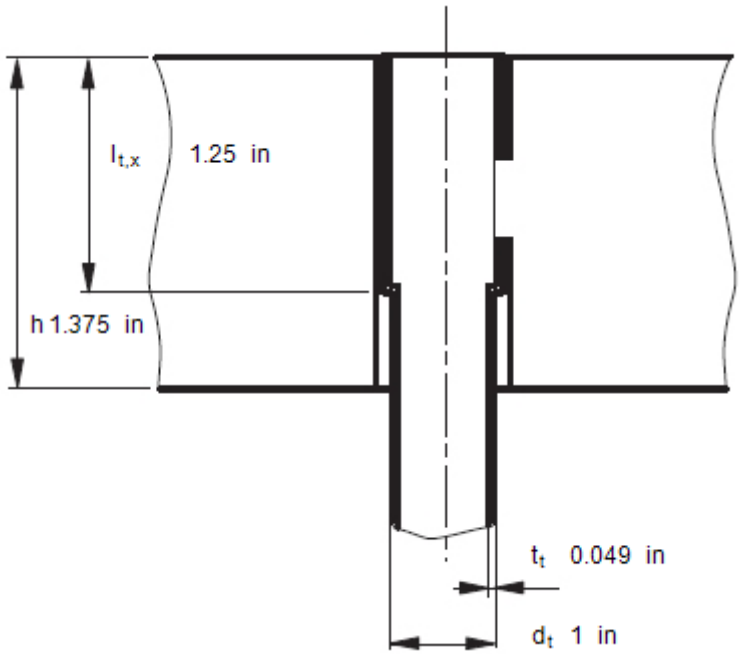
Configuration of the tubesheet (a, b, c, d)		Type	*a*	(a-d)
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	(1,2)
Internal operation pressure shell side		P_s	*325*	psi
Internal operation pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}	*325*	psi
Internal test pressure tube side		P_{tp}	*200*	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	*S30403-SA-240-304L-Class:-Size:*			
Tube material	*S30403-SA-249-TP304L-Class:-Size:*			
Shell material (Type abc)	*S30403-SA-240-304L-Class:-Size:*			
Channel material (Type a)	*K02700-SA-516-70-Class:-Size:*			

Operation	**Tubesheet**		**Tubes**		**Shell**		**Channel**	
Temperature	*400*	°F	*300*	°F	*400*	°F	*300*	°F
Thickness	*1.375*	in	*0.049*	in	*0.5625*	in	*0.375*	in
Outside diameter	*43.13*	in	*1*	in	*43.13*	in	*42.88*	in
Poiss.ratio	-		*0.3*		*0.3*		*0.3*	
Allow. c1	0	in	0	in	0	in	0	in
Corros. all. c_2	*0*	in	*0*	in	*0*	in	*0*	in
Properties for the selected load case temperature								
Strength op	15864	psi	14185	psi	15864	psi	20015	psi
Safety op.	1		1		1		1	
E-module	*2.64e+7*	psi	*2.699e+7*	psi	*2.64e+7*	psi	*2.829e+7*	psi
Therm.exp.	*9.462*	1E-6/°F	*9.217*	1E-6/°F	*9.462*	1E-6/°F	*6.885*	1E-6/°F
Yield str.	*17446*	psi	*19184*	psi	*17446*	psi	*33668*	psi
Limit temperature	896	°F	896	°F	896	°F	752	°F
All.stress	*15800*	psi	***14185***	psi	*15800*	psi	*20015*	psi
Pr.+sec.st	***47400***	psi			***47400***	psi	***67336***	psi
Properties for testing at 20°C								
Strength	22191	psi	22191	psi	22191	psi	33939	psi
Safety	1		1		1		1	
Yield str.	24656	psi	24656	psi	24656	psi	37710	psi
Tensile str.	70343	psi	70343	psi	70343	psi	70343	psi

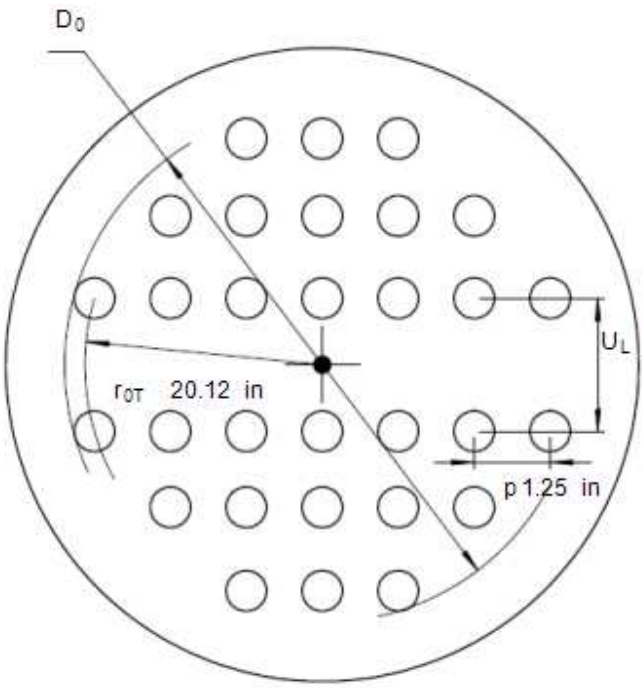
Additional specifications for the geometry and loading

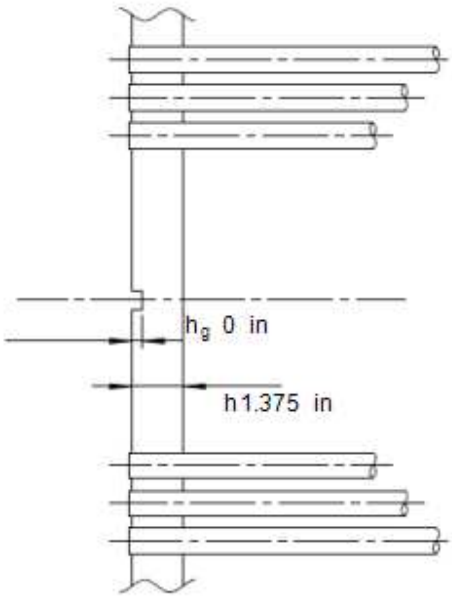
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		*1*	(1, 2)
Number of tubes		N_t	*955*	



Expanded length of tube in tubesheet		$l_{t,x}$	*1.25*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	*20.12*	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	*237.2*	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	*48*	in
Bellows inside diameter at its convolution height	D_j	*40*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	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}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.802*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.65*	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15800	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9109**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2713**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5434**	
Type abc: Coefficients for shell pressure	δ_S	**0.09301**	mm^3/N
β_S **4.458** 1/ft k_S **319697** lbf	λ_S	**5.087e+7**	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **5.464** 1/ft k_C **124426** lbf	λ_C	**2.204e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8370275**	lbf/in
Tube axial rigidity	K_t	**16652**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5264**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3					E*	7265202	psi
Ratio of elasticity tubesheet							E*/E	0.2752	
effective Poisson's ratio tubesheet							v*	0.3402	
Parameter for table UHX-13.1							X_a	7.013	
Z_d	0.004334	Z_v	0.02065	Z_m	0.2068	Z_a	294.8	Z_w	0.02065

Step 4

Diameter ratio = A/D0								K	1.045
F	6.728			Φ	9.017			Q_1	-0.05861
Q_{z1}	3.778			Q_{z2}	10.32			U	20.64

UHX-13.5.5 Step 5, coefficients

γ(*)	-0.08098	in		ω_S	4.613	in²		ω_S*	-4.541	in²
ω_C	3.344	in²		ω_C*	-2.629	in²		γ_b	0	

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'	613.4	psi		P_t'	543.4	psi		P_γ	-963.6	psi
P_W	0	psi		P_{rim}	46.1	psi		P_e	-144.5	psi

UHX-13.5.7 Step 7

Q_2	-331.7	lbf		Q_3	-0.04782			F_m	0.02391

Strength condition for the tubesheet bending stress, case 7

σ =	17187	psi	< 1.5 · σ_B =	1.5·	*15800*	psi		case 1-3
			< S_{PS} =		***47400***	psi		case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau =	1.45e+11	psi	< 0.8· σ_B =		12640	psi

Step 9: Shear stress Tau > 0.8*SigZul, tubesheet too thin

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

F_{tmin}	-0.3288		F_{tmax}	4.048	
x_{min}	3.17		x_{max}	7.013	
$\sigma_{T,1}$	-129.7	psi	$\sigma_{T,2}$	5914	psi

σ_{tmax} =	5914	psi	≤ σ_T =	***14185***	psi	for calculation case 1-3
			≤2 · σ_T =	28369	psi	for calculation case 4-7

Tube weld force W_t = 865.8 lbf ≤ $W_{t,all}$ = 0 lbf
(only when weld thickness < tube thickness: enter Wt,all>0 acc. UW-20)

r_t	0.3367	in	F_t	142.6		C_t	1.25	F_s	166.6

$\lvert\sigma_{tmin}\rvert$ =	-129.7	psi	$\lvert$ ≤S_{tb} =	8782	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 = *0.5625* in : (calculation case)

$\sigma_{Sm} \le$ *1·* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **1200** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

|**1200** psi| < Min(**6749** psi , **43039** psi)

ASME external pressure chart HA-3 A = **0.00326**

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

$\sigma_{Sm} \le$ *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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **11882** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = **1200** psi | + | **-10682** psi | ≤ **47400** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **49461** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = **5567** psi | + | **43894** psi | ≤ **67336** psi

Minimum shell length with uniform thickness l_{Sm} **8.75** in

Minimum channel thickness with uniform thickness l_{Cm} **7.154** 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	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.829e+7** psi	**2.829e+7** 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 = **11882** psi ≤ ***47400*** 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 = **49461** psi ≤ ***67336*** psi $=S_{PSc}$

Geometric conditions:

valid

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

13.4(d) If: Tube sheet thickness= *1.375* 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
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1465898\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2916\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186067\ \text{MPa}}{182023\ \text{MPa}} \cdot \frac{97.8\ \text{MPa}}{108.9\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.14\ \text{mm}}{23.14\ \text{mm}} = 0.2713$$

8 E4.18.7 (D1) plastic
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

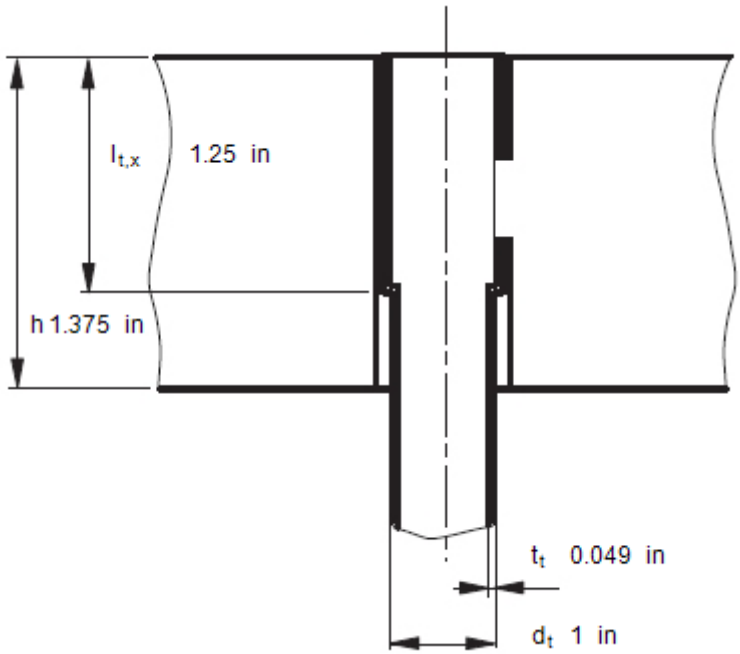
Configuration of the tubesheet (a, b, c, d)	Type	a	(a-d)
Tubesheet integral with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operation pressure shell side	P_s	325	psi
Internal operation pressure tube side	P_t	200	psi
Internal test pressure shell side	P_{sp}		psi
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	S30403-SA-240-304L-Class:-Size:		
Tube material	S30403-SA-249-TP304L-Class:-Size:		
Shell material (Type abc)	S30403-SA-240-304L-Class:-Size:		
Channel material (Type a)	K02700-SA-516-70-Class:-Size:		

Operation	**Tubesheet**		**Tubes**		**Shell**		**Channel**	
Temperature	400	°F	300	°F	400	°F	300	°F
Thickness	1.375	in	0.049	in	0.5625	in	0.375	in
Outside diameter	43.13	in	1	in	43.13	in	42.88	in
Poiss.ratio	-		0.3		0.3		0.3	
Allow. c1	0	in	0	in	0	in	0	in
Corros. all. c_2	0	in	0	in	0	in	0	in
Properties for the selected load case temperature								
Strength op	15864	psi	14185	psi	15864	psi	20015	psi
Safety op.	1		1		1		1	
E-module	2.649e+7	psi	2.699e+7	psi	2.649e+7	psi	2.829e+7	psi
Therm.exp.	9.462	1E-6/°F	9.217	1E-6/°F	9.462	1E-6/°F	6.885	1E-6/°F
Yield str.	17446	psi	19184	psi	17446	psi	33668	psi
Limit temperature	896	°F	896	°F	896	°F	752	°F
All.stress	15800	psi	14200	psi	15800	psi	20000	psi
Pr.+sec.st	**47400**	psi			**47400**	psi	**67336**	psi
Properties for testing at 20°C								
Strength	22191	psi	22191	psi	22191	psi	33939	psi
Safety	1		1		1		1	
Yield str.	24656	psi	24656	psi	24656	psi	37710	psi
Tensile str.	70343	psi	70343	psi	70343	psi	70343	psi

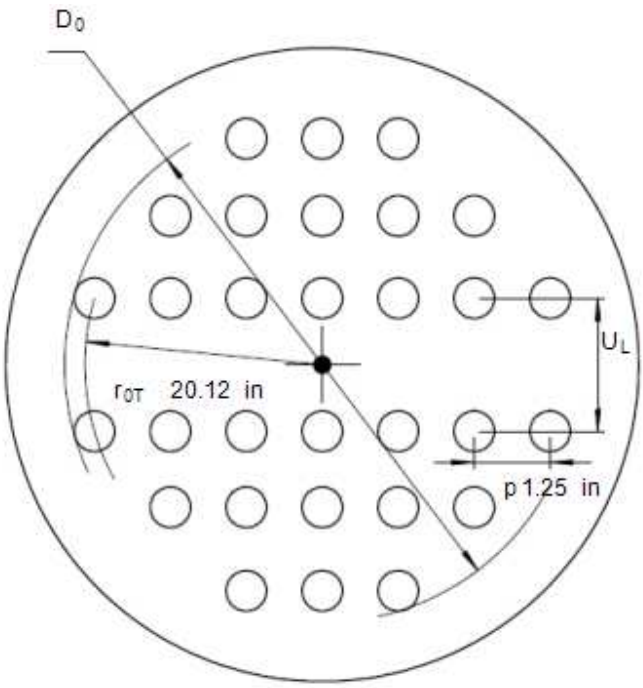
Additional specifications for the geometry and loading

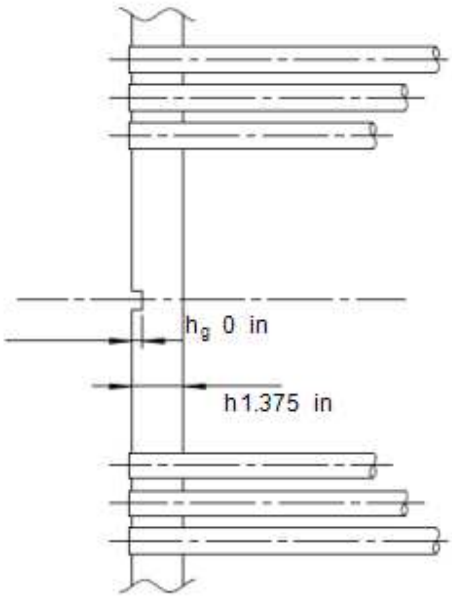
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		1	(1, 2)
Number of tubes		N_t	955	



Expanded length of tube in tubesheet		$l_{t,x}$	1.25	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	20.12	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	237.2	in
Unsupported tube span for buckling	l	48	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	**48**	in
Bellows inside diameter at its convolution height	D_j	40	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	1e+38	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}	151	°F
Mean temperature along the tube length	T_{tm}	113	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	8.802	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	8.65	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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)		N	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15800	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9112**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.271**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5434**	
Type abc: Coefficients for shell pressure	δ_S	**0.0927**	mm^3/N
β_S **4.458** 1/ft k_S **320789** lbf	λ_S	**5.104e+7**	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **5.464** 1/ft k_C **124426** lbf	λ_C	**2.204e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8398866**	lbf/in
Tube axial rigidity	K_t	**16652**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5282**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet		UHX-11.3					E^*	**7281414**	psi
Ratio of elasticity tubesheet							E^*/E	**0.2749**	
effective Poisson's ratio tubesheet							v^*	**0.3404**	
Parameter for table UHX-13.1							X_a	**7.009**	
Z_d	**0.004341**	Z_v	**0.02067**	Z_m	**0.2069**	Z_a	**293.3**	Z_w	**0.02067**

Step 4

Diameter ratio = A/D0							K	**1.045**	
F	**6.727**			Φ	**9.017**		Q_1	**-0.05867**	
Q_{z1}	**3.776**			Q_{z2}	**10.3**		U	**20.6**	

UHX-13.5.5 Step 5, coefficients

γ(*)	**0**	in		ω_S	**4.613**	in²	ω_S^*	**-4.541**	in²
ω_C	**3.344**	in²		ω_C^*	**-2.629**	in²	γ_b	**0**	

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'	**542.1**	psi	P_γ	**0**	psi
P_W	**0**	psi		P_{rim}	**-25.46**	psi	P_e	**-96.9**	psi

UHX-13.5.7 Step 7

Q_2	**183.5**	lbf		Q_3	**-0.06757**		F_m	**0.03378**	

Strength condition for the tubesheet bending stress, case 1

σ =	**16306**	psi	< 1.5 · σ_B =	1.5·	15800	psi		case 1-3
			< S_{PS} =		**47400**	psi		case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau = **1.45e+11** psi < 0.8· σ_B = **12640** psi

Step 9: Shear stress Tau > 0.8*SigZul, tubesheet too thin

Step 9, acc. to examples UHX-20.2:2009 (NOT latest version N)

F_q	**3.554**			F_s	**1.473**				

Strength condition for the tube stress with cacluation case 1:

$\lvert S_{To} \rvert$ =	**2253**	psi	≤ σ_T =	14200	psi		for calculation case 1-3
S_{To}			≤2 · σ_T =	**28400**	psi		for calculation case 4-7
S_{To}			≤S_{tb} =	**7452**	psi		(for STo<0, Buckling)
r_t	**0.3367**	in	F_t	**142.6**		C_t	**166.6**

Strength acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = 0.5625 in : (calculation case)

σ_{Sm} ≤	1·	15800	psi	=	$E_{sw}\cdot\sigma_{allS}$		(1-3)
σ_{Sm} =	**1832**	psi	≤2·	15800	psi	= $2\cdot\sigma_{allS}$	(4-7)

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

1832	psi	< Min(	**6749**	psi	,	**43186**	psi	)	
ASME external pressure chart		HA-3			A =	**0.00326**			

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: $\lvert \sigma_{Sm} \rvert$ < 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 =	$\lvert\sigma_{Sm}\rvert$	+	$\lvert\sigma_{Sb}\rvert$	=	**14996**	psi	≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}		
σ_S =	**1832**	psi	+		**-13164**	psi	≤	**23700**	psi
σ_C =	$\lvert\sigma_{Cm}\rvert$	+	$\lvert\sigma_{Cb}\rvert$	=	**33869**	psi	≤1.5 · σ_{allC} or S_{PSc}		
σ_C =	**5567**	psi	+		**28301**	psi	≤	**30000**	psi

Minimum shell length with uniform thickness	l_{Sm}	**8.75**	in
Minimum channel thickness with uniform thickness	l_{Cm}	**7.154**	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	**2.649e+7** psi	**2.649e+7** psi
Channel	**2.829e+7** psi	**2.829e+7** 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 = **14996** psi ≤ **47400** 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 = **33869** psi ≤ **67336** psi $=S_{PSc}$

Geometric conditions:

valid

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

13.4(d) If: Tube sheet thickness= 1.375 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
47400 psi = 3· 15800 psi or 2· 17446 psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1470905\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2916\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186067\ \text{MPa}}{182644\ \text{MPa}} \cdot \frac{97.91\ \text{MPa}}{108.9\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.14\ \text{mm}}{23.14\ \text{mm}} = 0.271$$

9 E4.18.7 (D2) plastic
ASME UHX-13 Fixed Tubesheets ASME BPVC Edition 2017

Fixed tubesheets according to ASME-UHX-13

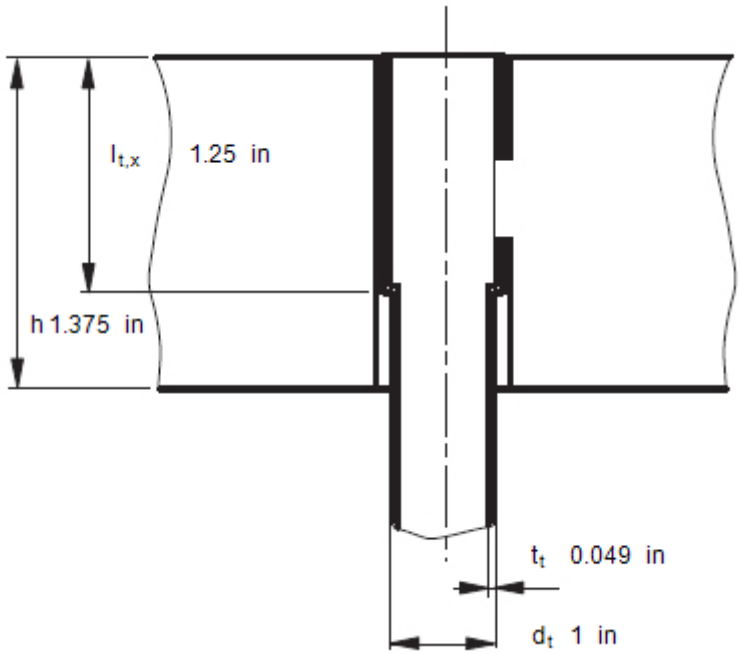
Configuration of the tubesheet (a, b, c, d)	Type	a	(a-d)
Tubesheet integral with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operation pressure shell side	P_s	325	psi
Internal operation pressure tube side	P_t	200	psi
Internal test pressure shell side	P_{sp}		psi
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	S30403-SA-240-304L-Class:-Size:		
Tube material	S30403-SA-249-TP304L-Class:-Size:		
Shell material (Type abc)	S30403-SA-240-304L-Class:-Size:		
Channel material (Type a)	K02700-SA-516-70-Class:-Size:		

Operation	**Tubesheet**	**Tubes**	**Shell**	**Channel**
Temperature	400 °F	300 °F	400 °F	300 °F
Thickness	1.375 in	0.049 in	0.5625 in	0.375 in
Outside diameter	43.13 in	1 in	43.13 in	42.88 in
Poiss.ratio	-	0.3	0.3	0.3
Allow. c1	0 in	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in	0 in
Properties for the selected load case temperature				
Strength op	15864 psi	14185 psi	15864 psi	20015 psi
Safety op.	1	1	1	1
E-module	2.649e+7 psi	2.699e+7 psi	2.649e+7 psi	2.829e+7 psi
Therm.exp.	9.462 1E-6/°F	9.217 1E-6/°F	9.462 1E-6/°F	6.885 1E-6/°F
Yield str.	17446 psi	19184 psi	17446 psi	33668 psi
Limit temperature	896 °F	896 °F	896 °F	752 °F
All.stress	15864 psi	16688 psi	15864 psi	20015 psi
Pr.+sec.st	47592 psi		47591 psi	67336 psi
Properties for testing at 20°C				
Strength	22191 psi	22191 psi	22191 psi	33939 psi
Safety	1	1	1	1
Yield str.	24656 psi	24656 psi	24656 psi	37710 psi
Tensile str.	70343 psi	70343 psi	70343 psi	70343 psi

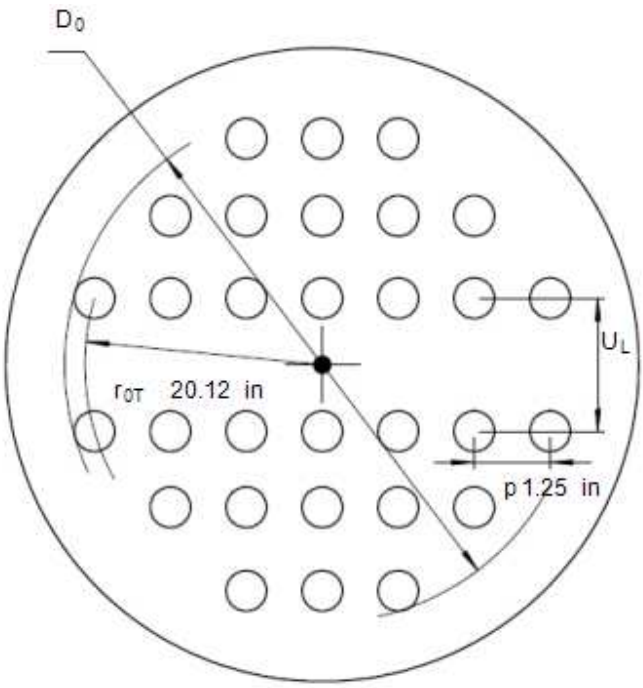
Additional specifications for the geometry and loading

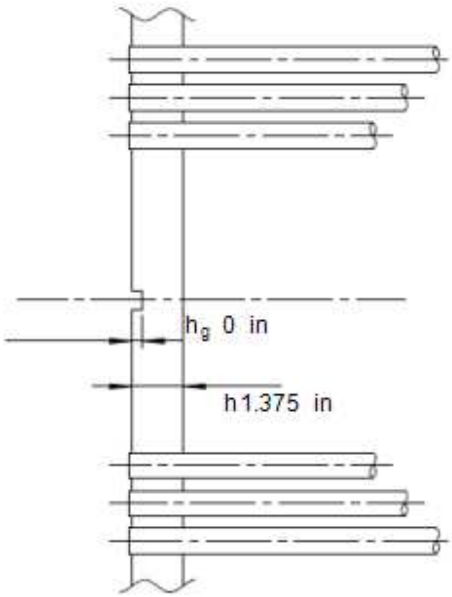
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1	(1, 2)
Tube pattern	(1=Triangle, 2=Square)		1	(1, 2)
Number of tubes		N_t	955	



Expanded length of tube in tubesheet		$l_{t,x}$	1.25	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.9091**	
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	20.12	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	237.2	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	48	in
Bellows inside diameter at its convolution height	D_j	40	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	1e+38	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}	151	°F
Mean temperature along the tube length	T_{tm}	113	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	8.788	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	8.656	1E-6/°F

Results acc. UHX-9		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		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)		N	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.12**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. UHX 11.5+13.5			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15800	psi
Tube material allowable stress safety at T	S_{fT}	1	-
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9116**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2707**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4388**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5434**	
Type abc: Coefficients for shell pressure	δ_S	**0.0927**	mm^3/N
β_S **4.458** 1/ft k_S **320789** lbf	λ_S	**5.104e+7**	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **5.464** 1/ft k_C **124426** lbf	λ_C	**2.204e+7**	psi

Step 2			
Shell axial rigidity K_s or K_s*	K_s	**8398866**	lbf/in
Tube axial rigidity	K_t	**16652**	lbf/in
Stiffness ratio $K_s/(N_t\cdot K_t)$	K_{st}	**0.5282**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet			UHX-11.3				E*	**7271269**	psi
Ratio of elasticity tubesheet							E*/E	**0.2745**	
effective Poisson's ratio tubesheet							v*	**0.3406**	
Parameter for table UHX-13.1							X_a	**7.011**	
Z_d	**0.004337**	Z_v	**0.02066**	Z_m	**0.2068**	Z_a	**294.1**	Z_w	**0.02066**

Step 4

Diameter ratio = A/D0							K	**1.045**	
F	**6.734**		Φ	**9.028**			Q_1	**-0.05867**	
Q_{z1}	**3.776**		Q_{z2}	**10.3**			U	**20.61**	

UHX-13.5.5 Step 5, coefficients

γ(*)	**0**	in	ω_S	**4.613**	in²		ω_S*	**-4.541**	in²
ω_C	**3.344**	in²	ω_C*	**-2.629**	in²		γ_b	**0**	

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'	**612.2**	psi	P_t'	**0**	psi		P_γ	**0**	psi
P_W	**0**	psi	P_{rim}	**71.49**	psi		P_e	**116.7**	psi

UHX-13.5.7 Step 7

Q_2	**-514.8**	lbf	Q_3	**-0.07941**			F_m	**0.0397**	

Strength condition for the tubesheet bending stress, case 2

σ =	**23103**	psi	< 1.5 · σ_B	=	1.5·	15864	psi	case 1-3
			< S_{PS}	=		47592	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

Tau =	**1.45e+11**	psi	< 0.8· σ_B	=	**12691**	psi

Step 9: Shear stress Tau > 0.8*SigZul, tubesheet too thin

Step 9, acc. to examples UHX-20.2:2009 (NOT latest version N)

F_q	**3.259**		F_s	**1.621**					

Strength condition for the tube stress with cacluation case 2:

$\lvert S_{To} \rvert$ =	**-2272**	psi	≤ σ_T	=	16688	psi		for calculation case 1-3
S_{To}			≤2 · σ_T	=	**33376**	psi		for calculation case 4-7
S_{To}			≤S_{tb}	=	**6773**	psi		(for STo<0, Buckling)
r_t	**0.3367**	in	F_t		**142.6**		C_t	**166.6**

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = 0.5625 in : (calculation case)

σ_{Sm} ≤	1·	15864	psi			=	$E_{sw}\cdot\sigma_{allS}$	(1-3)
σ_{Sm} =	**2287**	psi	≤2·	15864	psi	=	$2\cdot\sigma_{allS}$	(4-7)

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

2287	psi	< Min(	**6749**	psi	,	**43186**	psi	)	
ASME external pressure chart		HA-3			A =	**0.00326**			

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: $\lvert \sigma_{Sm} \rvert$ < 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 =	$\lvert\sigma_{Sm}\rvert$	+	$\lvert\sigma_{Sb}\rvert$	=	**28832**	psi	≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}		
σ_S =	**2287**	psi	+		**26546**	psi	≤	**23796**	psi
σ_C =	$\lvert\sigma_{Cm}\rvert$	+	$\lvert\sigma_{Cb}\rvert$	=	**8484**	psi	≤1.5 · σ_{allC} or S_{PSc}		
σ_C =	**0**	psi	+		**-8484**	psi	≤	**30023**	psi

Minimum shell length with uniform thickness	l_{Sm}	**8.75**	in
Minimum channel thickness with uniform thickness	l_{Cm}	**7.154**	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	**2.649e+7** psi	**2.649e+7** psi
Channel	**2.829e+7** psi	**2.829e+7** 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 = **28832** psi ≤ 47591 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 = **8484** psi ≤ 67336 psi =S_{PSc}

Geometric conditions:

valid

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

13.4(d) If: Tube sheet thickness= 1.375 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
47591 psi = 3· 15864 psi or 2· 17446 psi
(b) under the condition: SigZul not in the creep range:
T= 400 °F < 896 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 34.92\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 34.92\ \text{mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.2\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

UHX-13.5.2 Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1470905\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2916\ \text{N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{31.75\ \text{mm}}{34.92\ \text{mm}} = 0.9091$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^{\,2}}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm}^2}{\pi \cdot (1048\ \text{mm})^2}}} = 31.75\ \text{mm}$$

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

$$d1^* = (d_T - 2 \cdot t_T) = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm}) = d1^*$$

$$d2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186067\ \text{MPa}}{182644\ \text{MPa}} \cdot \frac{115.1\ \text{MPa}}{109.4\ \text{MPa}} \cdot 0.9091\right) = d2^*$$

$$\mu^* = \frac{p^* - d^*}{d^*} = \frac{31.75\ \text{mm} - 23.15\ \text{mm}}{23.15\ \text{mm}} = 0.2707$$

10 Comparison
Form for equations

Tables

with comment every three lines

Comparison of ASME example E4.18.7 and LV-calculation. Results arranged in 3 lines, line 1: LV calculation, line 2: ASME results, line 3: difference.

	Conversion factors			Step 1-2		Maximum		
	psi÷MPa	lb÷N	in÷mm	my*	Kst	J	betaS	Diff %
1	145	0.2248	0.03937	0.2713	0.5261	1	0.3715	
2	0	0	0	0.2711	0.526	1	0.3715	
3	0	0	0	0.0637	0.0173	0	-5.92e-4	0.0637

---- Step 2 ----

	kS	lambdaS	deltaS	betaC	kc	lambdaC	deltaC	MaxDiff%
4	319683	5.086e+7	2.525e-5	0.4554	124457	2.204e+7	3.553e-5	
5	319712	5.087e+7	2.524e-5	0.4554	124461	2.205e+7	3.553e-5	
6	-9.04e-3	-0.02216	0.03617	-0.01076	-3.45e-3	-0.02549	0.003124	0.03617

---- Step 3 ----

	ny*	E*	Xa	Zd	Zv	Zm	Za	MaxDiff%
7	0.3402	7263349	7.014	0.004332	0.02064	0.2068	295.2	
8	0.3404	7260000	7.016	0.00433	0.02067	0.2064	295.6	
9	-0.03546	0.04613	-0.01639	0.0461	-0.1275	0.1857	-0.1561	0.1857

---- Step 4 ----

	K	F	phi	Q1	Qz1	Qz2	U	MaxDiff%
10	1.045	6.728	9.018	-0.0586	3.779	10.32	20.65	
11	1.046	6.732	9.024	-0.05865	3.778	10.31	20.62	
12	-4.3e-3	-0.05655	-0.06578	-0.07443	0.02006	0.09872	0.09872	0.09872

---- Step 5 ----

	omS	om*S	omC	om*C	gammab			MaxDiff%
13	4.613	-4.541	3.344	-2.629	0			
14	4.612	-4.541	3.344	-2.603	0			
15	0.02099	0.001365	-7.78e-4	0.9918	0	0	0	0.9918

---- Step 5+6 for calculation case 7 ----

	gamma	Ps'	Pt'	Pgamma	PW	Prim	Pe	MaxDiff%
16	-0.08098	613.2	543.3	-963.4	0	46.09	-144.4	
17	-0.0809	613.7	543.7	-963	0	46.3	-144.3	
18	0.09523	-0.07637	-0.07289	0.03655	0	-0.449	0.08198	0.449

--- Step 6: Prim for case 1-7 ---

Prim:	1 D1	2 D2	3 D3	4 O4	5 O1	6 O2	7 O3	MaxDiff%
19	-25.51	71.59	46.09	0	-25.5	71.59	46.09	
20	-25.2	71.6	46.3	0	-25.2	71.6	46.3	
21	1.219	-0.01158	-0.449	0	1.189	-0.01158	-0.449	1.219

--- Step 6: Pe for case 1-7 ---

Pe:	1 D1	2 D2	3 D3	4 O4	5 O1	6 O2	7 O3	MaxDiff%
22	-96.96	116.7	19.77	-164.2	-261.1	-47.47	-144.4	
23	-97	116.8	19.8	-164.1	-261.1	-47.3	-144.3	
24	-0.0463	-0.06815	-0.1301	0.05637	0.01478	0.364	0.08198	0.364

--- Step 7: Q2 for case 1-7 ---

Q2:	1 D1	2 D2	3 D3	4 O4	5 O1	6 O2	7 O3	MaxDiff%
25	183.5	-515.2	-331.7	0	183.5	-515.2	-331.7	
26	181.7	-515.1	-333.4	0	181.7	-515.1	-333.4	
27	1.003	0.02644	-0.5043	0	1	0.02644	-0.5043	1.003

--- Step 7: Q3 for case 1-7 ---

Q3:	1 D1	2 D2	3 D3	4 O4	5 O1	6 O2	7 O3	MaxDiff%
28	-0.0675	-0.07936	-0.1375	-0.05861	-0.06192	-7.6e-3	-0.04782	
29	-0.0675	-0.0794	-0.138	-0.0587	-0.0619	-7.49e-3	-0.0478	
30	0.001156	-0.04805	-0.3876	-0.1492	0.02546	1.409	0.03272	1.409

Links

```
1  1 UHXb: psi÷MPa = 145: lb÷N = 0.2248: in÷mm=0.03937: #88: #198: #113: #121/in÷mm
2  10 EQU: : : : 0.2711: 0.526: 1: 0.3715
3
4  1 UHXb: #122*lb÷N: #123*psi÷MPa: #124*in÷mm^3/lb÷N: #126/in÷mm: #127*lb÷N: #128*psi÷MPa: #129*in÷mm^3/lb÷N
5  10 EQU: 319712: 50867972: 25.24E-6: 0.4554: 124461: 22049112: 35.532E-6
6
7  1 UHXb: #100: #98*psi÷MPa: #120: #203: #204: #205: #304
8  10 EQU: 0.340361: 7.26E6: 7.0155: 0.00433: 0.0206712: 0.20637: 295.63
9
10 1 UHXb: #131: #132: #206: #207: #208: #209: #210
11 10 EQU: 1.0455: 6.7322: 9.0236: -0.058647: 3.7782: 10.3124: 20.6248
12
13 1 UHXb: #125*in÷mm^2: #136*in÷mm^2: #130*in÷mm^2: #135*in÷mm^2: #134
14 10 EQU: 4.6123: -4.5413: 3.344 : -2.6027: 0
15

16 7 UHXb: #137*in÷mm: #255*psi÷MPa: #256*psi÷MPa: #257*psi÷MPa: #258*psi÷MPa: #259*psi÷MPa: #260*psi÷MPa
17 10 EQU: -0.0809: 613.7: 543.7: -963: 0: 46.3: -144.3
18
19 1 UHXb: #259(1)*psi÷MPa: #259(2)*psi÷MPa: #259(3)*psi÷MPa: #259(4)*psi÷MPa: #259(5)*psi÷MPa: #259(6)*psi÷MPa: #259
20 10 EQU: -25.2: 71.6: 46.3: 0: -25.2: 71.6: 46.3
21
22 1 UHXb: #260(1)*psi÷MPa: #260(2)*psi÷MPa: #260(3)*psi÷MPa: #260(4)*psi÷MPa: #260(5)*psi÷MPa: #260(6)*psi÷MPa: #
23 10 EQU: -97: 116.8: 19.8: -164.1: -261.1: -47.3: -144.3
24
25 1 UHXb: #153(1)*lb÷N: #153(2)*lb÷N: #153(3)*lb÷N: #153(4)*lb÷N: #153(5)*lb÷N: #153(6)*lb÷N: #153(7)*lb÷N
26 10 EQU: 181.7: -515.1: -333.4: 0: 181.7: -515.1: -333.4
27
28 1 UHXb: #133(1): #133(2): #133(3): #133(4): #133(5): #133(6): #133(7)
29 10 EQU: -0.0675: -0.0794: -0.138: -0.0587: -0.0619: -0.00749: -0.0478
30
```

Additional comments

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

11 Comparison
Form for equations

Tables

with comment every three lines

Results for calculation case 1-7 arranged in 3 lines,
line 1: LV calculation, line2: ASME, line 3: difference in %.
Results for calculation case 1 - 7

:	psi÷MPa :	lb÷N :	in÷mm :					
1	145	0.2248	0.03937	0	0	0	0	
2	145	0.2248	0.03937	0	0	0	0	
3	0	0	0	0	0	0	0	0
Fm:-----	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
4	0.03375	0.03968	0.06873	0.02931	0.03096	0.03208	0.02391	
5	0.03373	0.03969	0.06886	0.02932	0.03096	0.0321	0.02389	
6	0.06045	-0.02288	-0.1851	-0.04703	-6.85e-3	-0.07065	0.07459	0.1851
|Sig|:--	Case 1 :	D1 2 :	D2 3 :	O4 4 :	O1 5 :	O2 6 :	O3 7 :	MaxDiff%
7	16285	23049	6764	23946	40232	7578	17183	
8	16286	23084	6798	23967	40253	7566	17169	
9	-8.6e-3	-0.1507	-0.5033	-0.08587	-0.05257	0.1609	0.07939	0.5033
|Tau|:--	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
10	1.45e+11	1.45e+11	0	1.45e+11	1.45e+11	0	1.45e+11	
11	3636	4380	744	6155	9792	1775	5412	
12	3.988e+9	3.311e+9	-100	2.356e+9	1.481e+9	-100	2.679e+9	3.988e+9
Ftmin:--	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
13	-0.2705	-0.2431	-0.1907	-0.2949	-0.2855	-0.4896	-0.3288	
14	-0.27	-0.243	-0.191	-0.295	-0.285	-0.49	-0.329	
15	0.1945	0.02453	-0.1715	-0.01736	0.1782	-0.07641	-0.06997	0.1945

St1:----	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
16	-1289	1634	360.2	-462.9	-1751	1141	-129.7	
17	-1290	1634	360.4	-462.4	-1751	1142	129.1	
18	-0.01939	-0.02552	-0.05391	0.1129	9.137e-4	-0.08638	0.4611	0.4611
Ftmax:--	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
19	3.557	3.26	2.126	3.778	3.696	5.053	4.048	
20	3.558	3.26	2.123	3.778	3.696	5.057	4.05	
21	-0.03856	0.003466	0.1406	0.01244	-1.46e-3	-0.07987	-0.04462	0.1406
St2:----	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
22	2258	-2275	-77.69	5930	8187	3656	5913	
23	2259	-2277	-78.2	5928	8187	3652	5911	
24	-0.07104	-0.08478	-0.6537	0.03723	-1.43e-3	0.1132	0.03067	0.6537

Value Stmax by ASME for case 2 is a typing error:

Stmax:--1	D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
25	2258	1634	360.2	5930	8187	3656	5913	
26	2259	-2277	360.4	5928	8187	3652	5911	
27	-0.05777	0	-0.05391	0.03892	0.003457	0.09953	0.02729	0.09953
Stmin:--	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
28	-1289	-2275	-77.69	-462.9	-1751	1141	-129.7	
29	1290	2277	78.2	462.4	1751	0	129	
30	-0.01939	-0.08478	-0.6537	0.1129	9.137e-4	0	0.539	0.6537

Links

1 1 UHXb: psi÷MPa = 145: lb÷N = 0.2248: in÷mm=0.03937: : : :
2 11 EQU: 145: 0.2248: 0.03937: : : :
3
4 1 UHXb: #261(1): #261(2): #261(3): #261(4): #261(5): #261(6): #261(7)
5 11 EQU: 0.03373: 0.03969: 0.06886: 0.02932: 0.03096: 0.03210: 0.02389
6
7 1 UHXb: #138(1)*psi÷MPa: #138(2)*psi÷MPa: #138(3)*psi÷MPa: #138(4)*psi÷MPa: #138(5)*psi÷MPa: #138(6)*psi÷MPa: #138
8 11 EQU: 16286: 23084: 6798: 23967: 40253: 7566: 17169
9
10 1 UHXb: #140(1)*psi÷MPa: #140(2)*psi÷MPa: #140(3)*psi÷MPa: #140(4)*psi÷MPa: #140(5)*psi÷MPa: #140(6)*psi÷MPa: #140
11 11 EQU: 3636: 4380: 744: 6155: 9792: 1775: 5412
12
13 1 UHXb: #305: #305(2): #305(3): #305(4): #305(5): #305(6): #305(7)
14 11 EQU: -.27: -.243: -.191: -.295: -.285: -.490: -.329
15

16 1 UHXb: #311*psi÷MPa: #311(2)*psi÷MPa: #311(3)*psi÷MPa: #311(4)*psi÷MPa: #311(5)*psi÷MPa: #311(6)*psi÷MPa: #311(7)
17 11 EQU: -1289.5: 1634.3: 360.4: -462.4: -1751.2: 1141.5: 129.1
18
19 1 UHXB: #306: #306(2): #306(3): #306(4): #306(5): #306(6): #306(7)
20 11 EQU: 3.558:3.260: 2.123: 3.778: 3.696: 5.057: 4.050
21
22 1 UHXb: #312*psi÷MPa: #312(2)*psi÷MPa: #312(3)*psi÷MPa: #312(4)*psi÷MPa: #312(5)*psi÷MPa: #312(6)*psi÷MPa: #312(7)
23 11 EQU: 2259.3: -2276.6: -78.2: 5928.1: 8187.4: 3651.5: 5910.8
24
25 1 UHXb: #316*psi÷MPa: #316(2)*psi÷MPa: #316(3)*psi÷MPa: #316(4)*psi÷MPa: #316(5)*psi÷MPa: #316(6)*psi÷MPa: #316(7)
26 11 EQU: 2259: -2277: 360.4: 5928: 8187: 3652: 5911
27
28 1 UHXb: #315*psi÷MPa: #315(2)*psi÷MPa: #315(3)*psi÷MPa: #315(4)*psi÷MPa: #315(5)*psi÷MPa: #315(6)*psi÷MPa: #315(7)
29 11 EQU: 1289.5: 2276.6: 78.2: 462.4: 1751.2: :129
30

Additional comments

12 Comparison
Form for equations

Tables

with comment every three lines

Results for calculation case 1-7 arranged in 3 lines,
line 1: LV calculation, line2: ASME, line 3: difference in %.
Results for calculation case 1 - 7

	: psi÷MPa :	lb÷N :	in÷mm :					
1	145	0.2248	0.03937	0	0	0	0	
2	145	0.2248	0.03937	0	0	0	0	
3	0	0	0	0	0	0	0	0
Fs:-----	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
4	1.472	1.62	2	1.361	1.402	0	1.25	
5	1.471	1.62	2	1.361	1.402	0	1.25	
6	0.04663	-3.46e-3	0	-0.01727	0.001926	0	0	0.04663
Stb:----	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
7	7458	6774	5487	8065	7827	0	8779	
8	7468	6781	5493	8072	7837	0	8788	
9	-0.1292	-0.09596	-0.1065	-0.0892	-0.1155	0	-0.09744	0.1292
SigSm:--	1 D1 :	2 D2	: 3 D3	: 4 O4	: 5 O1	: 6 O2	: 7 O3	: MaxDiff%
10	1830	2287	4117	-2917	-1087	-630.1	1200	0
11	1831	2287	4118	-2917	-1086	-629.3	1201	
12	-0.04458	-0.0139	-0.02365	0.01807	0.1091	0.1343	-0.125	0.1343

ASME used possibly formulas acc. Add.2008, see '14 2008':

SigSb:--1---:----2---:----3---:----4---:----5---:---6(*)-:----7---:MaxDiff%							
13	-12164	27758	15592	-26271	-38437	1487	-10679	0
14	-13168	26519	13350	-24666	-37834	1853	-11315	
15	-7.623	4.671	16.79	6.508	1.594	-19.78	-5.619	19.78

SigCm:--1---:----2---:----3---:----4---:----5---:----6---:----7---:MaxDiff%							
16	5566	0	5566	0	5566	0	5566	
17	5567	0	5567	0	5567	0	5567	
18	-0.02346	0	-0.02346	0	-0.02346	0	-0.02346	0.02346
SigCb:--1---:----2---:----3---:----4---:----5---:----6---:----7---:MaxDiff%							
19	28324	-8502	19821	24062	52384	15561	43883	
20	28346	-8492	19854	24033	52380	15541	43887	
21	-0.07691	0.112	-0.1675	0.1215	0.008534	0.1267	-9.21e-3	0.1675

Links

1	1 UHXb: psi÷MPa = 145: lb÷N = 0.2248: in÷mm=0.03937: : : :
2	12 EQU: 145: 0.2248: 0.03937: : : :
3	
4	1 UHXb: #268: #268(2): #268(3): #268(4): #268(5): :#268(6)
5	12 EQU: 1.471: 1.620: 2: 1.361: 1.402: :1.25
6	
7	1 UHXb: psi÷MPa*#269: psi÷MPa*#269(2): psi÷MPa*#269(3) : psi÷MPa*#269(4): psi÷MPa*#269(5): : psi÷MPa*#269(6)
8	12 EQU: 7468: 6781: 5493: 8072: 7836.5: :8788
9	
10	1 UHXb: #142(1)*psi÷MPa: #142(2)*psi÷MPa: #142(3)*psi÷MPa: #142(4)*psi÷MPa: #142(5)*psi÷MPa: #142(6)*psi÷MPa : #142
11	12 EQU: 1830.6: 2287.2: 4117.8: -2916.5: -1085.9: -629.3: 1201.3
12	
13	1 UHXb: #143(1)*psi÷MPa: #143(2)*psi÷MPa: #143(3)*psi÷MPa: #143(4)*psi÷MPa: #143(5)*psi÷MPa: #143(6)*psi÷MPa : #143
14	12 EQU: -13168.2: 26519: 13350: -24666: -37834: 1853: -11315
15	

16 1 UHXb: #146(1)*psi÷MPa: #146(2)*psi÷MPa: #146(3)*psi÷MPa: #146(4)*psi÷MPa: #146(5)*psi÷MPa: #146(6)*psi÷MPa: #146
17 12 EQU: 5567: 0: 5567: 0: 5567: 0: 5567
18
19 1 UHXb: #147(1)*psi÷MPa: #147(2)*psi÷MPa: #147(3)*psi÷MPa: #147(4)*psi÷MPa: #147(5)*psi÷MPa: #147(6)*psi÷MPa: #147
20 12 EQU: 28346: -8492: 19854: 24033: 52380: 15541: 43887
21
22
23
24
25
26
27
28
29
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Additional comments

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

Appendix: Material documentation

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

Material specification:

Regulation:	ASMET1A:2013	Spec. No.:	SA-240	Product:	Plate
Material code:	S30403-SA-240-304L-Class:-	Size:		Short name:	18Cr-8Ni

Design conditions and dimensions:

Temperature [°C]:	204,4444	Pressure [bar]:	0
Thickness [mm]:	34,92	Outside diameter [mm]:	1095,38

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	115,00	109,38
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	115,00	109,38
Modulus of elasticity [kN/mm²]:	195	182,6445

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
		115	115	110	103	97.7	94.1	91.3

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
	88.7	72.5	49.5	32.9	22.0		

Modulus of elasticity in dependence of the temperature:

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

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

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

600	700			
151	140			

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

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

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

Material specification:

Regulation:	ASMET1A:2013Spec. No.: SA-249	Product:	Wld. tube
Material code:	S30403-SA-249-TP304L-Class:-Size:	Short name:	18Cr-8Ni

Design conditions and dimensions:

Temperature [°C]:	148,89	Pressure [bar]:	0
Thickness [mm]:	1,24	Outside diameter [mm]:	25,4

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	97,80	97,80
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	97,80	97,80
Modulus of elasticity [kN/mm²]:	195	186,0666

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

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

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
	97.8	97.8	93.2	87.2	83.0	80.0	77.6	

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
	75.4	61.6	42.1	28.0	18.7		

Modulus of elasticity in dependence of the temperature:

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

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

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

600	700			
151	140			

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

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

Section 1: Vorkammer/UHXb
Section 1: Vorkammer-Zeitst/UHXb
Section 2: Vorkammer/UHXb
Section 2: Vorkammer-Zeitst/UHXb
Section 3: Vorkammer/UHXb
Section 3: Vorkammer-Zeitst/UHXb
Section 4: Vorkammer/UHXb
Section 4: Vorkammer-Zeitst/UHXb
Section 5: Vorkammer/UHXb
Section 5: Vorkammer-Zeitst/UHXb
Section 6: Vorkammer/UHXb
Section 6: Vorkammer-Zeitst/UHXb
Section 7: Vorkammer/UHXb
Section 7: Vorkammer-Zeitst/UHXb
Section 8: Vorkammer/UHXb
Section 8: Vorkammer-Zeitst/UHXb
Section 9: Vorkammer/UHXb
Section 9: Vorkammer-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]: 148,8889 Pressure [bar]: 0
Thickness [mm]: 9,52 Outside diameter [mm]: 1089,03

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	138,00	138,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	138,00	138,00
Modulus of elasticity [kN/mm²]:	202	195,0667

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

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

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		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: Boden-Zeitst/UHXb
Section 2: Boden-Zeitst/UHXb
Section 3: Boden-Zeitst/UHXb
Section 4: Boden-Zeitst/UHXb
Section 5: Boden-Zeitst/UHXb
Section 6: Boden-Zeitst/UHXb
Section 7: Boden-Zeitst/UHXb
Section 8: Boden-Zeitst/UHXb
Section 9: Boden-Zeitst/UHXb

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-240 Product: Plate
Material code: S30403-SA-240-304L-Class:-Size: Short name: 18Cr-8Ni

Design conditions and dimensions:

Temperature [°C]: 204,44 Pressure [bar]: 0
Thickness [mm]: 34,92 Outside diameter [mm]: 1095,38

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	115,00	109,38
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	115,00	109,38
Modulus of elasticity [kN/mm²]:	195	182,6448

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

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

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		115	115	110	103	97.7	94.1	91.3

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
	88.7	72.5	49.5	32.9	22.0		

Modulus of elasticity in dependence of the temperature:

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

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

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

600	700
151	140

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

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

Section 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
Section 9: mittlere W-dehn. Mantel/UHXb

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-240 Product: Plate
Material code: S30403-SA-240-304L-Class:-Size: Short name: 18Cr-8Ni

Design conditions and dimensions:

Temperature [°C]: 66,11 Pressure [bar]: 0
Thickness [mm]: 14,29 Outside diameter [mm]: 1095,5

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	115,00	115,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	115,00	115,00
Modulus of elasticity [kN/mm²]:	195	191,7112

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
		115	115	110	103	97.7	94.1	91.3

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
	88.7	72.5	49.5	32.9	22.0		

Modulus of elasticity in dependence of the temperature:

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

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

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

600	700
151	140

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

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

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

Material specification:

Regulation:	ASMET1A:2013	Spec. No.:	SA-249	Product:	Wld. tube
Material code:	S30403-SA-249-TP304L-Class:	-Size:		Short name:	18Cr-8Ni

Design conditions and dimensions:

Temperature [°C]:	45	Pressure [bar]:	0
Thickness [mm]:	1,24	Outside diameter [mm]:	25,4

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	97,80	97,80
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	97,80	97,80
Modulus of elasticity [kN/mm²]:	195	193,4

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

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

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		97.8	97.8	93.2	87.2	83.0	80.0	77.6

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
	75.4	61.6	42.1	28.0	18.7		

Modulus of elasticity in dependence of the temperature:

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

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

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

600	700
151	140

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

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

Section 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
Section 9: Bodenrand-3/UHXb
Section 9: Schale-Rand-3/UHXb

Material specification:

Regulation: ASMET1A:2013Spec. No.: SA-240 Product: Plate
Material code: S30403-SA-240-304L-Class:-Size: Short name: 18Cr-8Ni

Design conditions and dimensions:

Temperature [°C]: 20 Pressure [bar]: 0
Thickness [mm]: 34,92 Outside diameter [mm]: 1095,38

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	115,00	115,00
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	115,00	115,00
Modulus of elasticity [kN/mm²]:	195	195

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
		115	115	110	103	97.7	94.1	91.3

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
	88.7	72.5	49.5	32.9	22.0		

Modulus of elasticity in dependence of the temperature:

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

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

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

600	700			
151	140			

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

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

Section 1: Vorkammer-Rand-3/UHXb
Section 2: Vorkammer-Rand-3/UHXb
Section 3: Vorkammer-Rand-3/UHXb
Section 4: Vorkammer-Rand-3/UHXb
Section 5: Vorkammer-Rand-3/UHXb
Section 6: Vorkammer-Rand-3/UHXb
Section 7: Vorkammer-Rand-3/UHXb
Section 8: Vorkammer-Rand-3/UHXb
Section 9: Vorkammer-Rand-3/UHXb

Material specification:

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

Design conditions and dimensions:

Temperature [°C]:	20	Pressure [bar]:	0
Thickness [mm]:	9,52	Outside diameter [mm]:	1089,03

Material values for test and design conditions:

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

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

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

K-values as function of the temperature

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

K-values as function of the temperature

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

Modulus of elasticity in dependence of the temperature:

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

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

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

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

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

Material specification:

Regulation:	ASMET1A:2013	Spec. No.:	SA-249	Product:	Wld. tube
Material code:	S30403-SA-249-TP304L-Class:-	Size:		Short name:	18Cr-8Ni

Design conditions and dimensions:

Temperature [°C]:	204,44	Pressure [bar]:	0
Thickness [mm]:	1,24	Outside diameter [mm]:	25,4

Material values for test and design conditions:

	Test condition	Operating condition
Nominal design strength [N/mm²]:	97,80	92,67
Safety factor:	1,00	1,00
Allowable stress [N/mm²]:	97,80	92,67
Modulus of elasticity [kN/mm²]:	195	182,6448

Creep rupture strength for 100000 h [MPa]:

Tensile strength and yield stress at ambient temperature:

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

K-values as function of the temperature

Diam./ Thickn. <= mm	50°C MPa	100°C MPa	150°C MPa	200°C MPa	250°C MPa	300°C MPa	350°C MPa	400°C MPa
		97.8	97.8	93.2	87.2	83.0	80.0	77.6

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
	75.4	61.6	42.1	28.0	18.7		

Modulus of elasticity in dependence of the temperature:

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

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146	201	209	204	195	189	186	183	179	176	172	169	165	160	156

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

600	700
151	140

Coefficient of linear expansion:

Thermal coefficient of expansion between 20°C and

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