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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

Strength Calculation Software	Program System ATLAS	Version	**10.0.98**
Developed by Lauterbach Verfahrenstechnik GmbH			
Certified per DIN EN ISO 9001:2015	Certificate Number 01 100 044763		

Example 4.18.1 - U Tubesheet Exchanger , Configuration a

Step 1

		LV Soft				ASME		Diff [%]
Equivalent diameter	D_0	295,300	mm	1,16E+01	in	1,16E+01	in	**0,00%**
Basic ligamnet efficient	μ	0,250		2,50E-01	in	2,50E-01		**0,00%**
Effective ligament efficiency	h'_g	0,000	mm	0,00E+00	in	0,00E+00	in	**0,00%**

Step 2

		LV Soft				ASME		Diff [%]
Ratio Ds/D0	ρ_S	1,066		1,07E+00		1,07E+00		**0,40%**
Ratio Dc/D0	ρ_C	1,059		1,06E+00		1,06E+00		**0,08%**
Tubesheet rim moment	M_{TS}	-713,331	N	-1,60E+02	lbf	-1,60E+02	lbf	**-0,23%**

Step 3

		LV Soft				ASME		Diff [%]
Effective mod. Elasticity	**E***	79427,48	Mpa	1,15E+07	psi	1,15E+07	psi	**0,17%**
Effective Poisson's ratio	**v***	0,25		2,54E-01		2,54E-01		**0,03%**
Effective tube pitch	**p***	29,26	mm	1,15E+00	in	1,15E+00	in	**0,18%**
Effective ligament efficient	**μ***	0,35		3,49E-01		3,49E-01		**0,01%**
Effective tube hole diameter	**d***	19,05	mm	7,50E-01	in	7,50E-01	in	**0,00%**

Step 4

		LV Soft				ASME		Diff [%]
Coefficient for shell pressure	δ_S	0,03	mm^3/N	7,00E-06	in^3/lb	7,02E-06	in^3/lb	**0,11%**
Coefficient for moment	ω_S	316,78	mm^2	4,91E-01	in^2	4,91E-01	in^2	**0,00%**
Coefficient for channel pressure	δ_C	0,01	mm^3/N	3,98E-06	in^3/lb	3,99E-06	in^3/lb	**0,09%**
Coefficient for moment	ω_C	487,71	mm^2	7,56E-01	in^2	7,56E-01	in^2	**0,01%**

Step 5

		LV Soft	ASME	Diff [%]
Diameter ration A/D0	**K**	1,11E+00	1,11E+00	**0,27%**
Coefficient	**F**	9,41E+00	9,41E+00	**0,05%**

Step 6

		LV Soft				ASME		Diff [%]
Rim moment	**M***	-220,72	N	-4,96E+01	lb/in	-4,94E+01	lb/in	**-0,44%**

Step 7

		LV Soft				ASME		Diff [%]
Bending moment at periphery	M_P	2526,27	N	5,68E+02	lb/in	5,68E+02	lb/in	**0,01%**
Moment at the tubesheet center	M_0	-2059,05	N	-4,63E+02	lb/in	-4,63E+02	lb/in	**-0,02%**

Step 8

		LV Soft				ASME		Diff [%]
Bending stress	σ	248,02	N	3,60E+04	psi	3,60E+04	psi	**0,00%**
Bending stress	$2\sigma_B$	249,20	N	3,61E+04	psi	3,60E+04	psi	**0,40%**

Step 9

		LV Soft				ASME		Diff [%]
Shear stress	τ	23,08	N	3,35E+03	psi	3,35E+03	psi	**0,08%**
Shear stress (Min 0,8σB; 0,533Sy)		73,45	N	1,07E+04	psi	1,07E+04	psi	**0,00%**

Step 10

	LV Soft				ASME		Diff [%]
σ_S	122,38	N	1,78E+04	psi	1,77E+04	psi	**0,28%**
$1{,}5.\sigma_{all}$	186,90	N	2,71E+04	psi	2,70E+04	psi	**0,40%**
$\sigma_{S,m}$	-1,17	N	1,70E+02	psi	-1,70E+02	psi	**-0,22%**
$\sigma_{S,b}$	-121,21	N	1,76E+04	psi	-1,76E+04	psi	**-0,11%**
σ_C	183,55	N	2,66E+04	psi	2,66E+04	psi	**0,08%**
$1{,}5.\sigma_{all}$	186,90	N	2,71E+04	psi	2,70E+04	psi	**0,40%**
$\sigma_{c,m}$	9,26	N	1,34E+03	psi	1,34E+03	psi	**0,21%**
$\sigma_{c,b}$	174,29	N	2,53E+04	psi	2,53E+04	psi	**0,08%**

E 4.18.1 - U-Tubesheets - ASME BPVC VIII-1, UHX-12: 2021

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

Configuration of the tubesheet		a	
Tubesheet integral with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operating pressure shell side	P_s	-10	psi
Internal operating pressure tube side	P_t	140	psi
Internal test pressure shell side	P_{sp}	-13	psi
Internal test pressure tube side	P_{tp}	182	psi
Load case (1=Operation, 2+3=Test at 20°C, 4=other)		1	
load case: operation			
Calculation case UHX12.4(a) (1: Ps=0, 2: Pt=0, 3:Differ.)		3	(1-3)
Shell and tube side pressure acting			
Material tubesheet	S31600-SA-240-316-Class:-Size:		
Material shell (Type abc)	S31600-SA-312-TP316-Class:-Size:		
Material tubes	S31600-SA-213-TP316-Class:-Size:		
Mat. channel (Type aef)	S31600-SA-240-316-Class:-Size:		

Load temperature°C	**Tubesheet**	**Shell**	**Tubes**	**Channel**
Temperat.	500 °F	500 °F	500 °F	500 °F
Thickness	0.521 in	0.18 in	0.065 in	0.313 in
Outside diameter	12.94 in	12.75 in	0.75 in	12.94 in
Strength	18072 psi	18072 psi	18072 psi	18072 psi
Safety fac.	1	1	1	1
Modulus of elasticity	2.587e+7 psi	2.587e+7 psi	2.587e+7 psi	2.587e+7 psi
Allow. c_1	0 in	0 in	0 in	0 in
Corr.all. c_2	0 in	0 in	0 in	0 in
Poisson's ratio	v	0.3		0.3
Therm.exp.	9.678 1E-6/°F	9.678 1E-6/°F	9.678 1E-6/°F	9.678 1E-6/°F
Yield str.	19986 psi	19986 psi	19986 psi	19986 psi
Limit temperature	32 °F	32 °F	32 °F	32 °F
All.Stress	**18072** psi	**18072** psi	**18072** psi	**18072** psi
Pr.+sec.st	**54215** psi	**54215** psi	**54215** psi	**54215** psi
Test 20°C	**Tubesheet**	**Shell**	**Tubes**	**Channel**
Strength	26759 psi	26759 psi	26759 psi	26759 psi
Safety fac.	1	1	1	1
Modulus of elasticity	2.833e+7 psi	2.833e+7 psi	2.833e+7 psi	2.833e+7 psi
Yield str.	29733 psi	29733 psi	29733 psi	29733 psi
Tensile str.	74694 psi	74694 psi	74694 psi	74694 psi

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

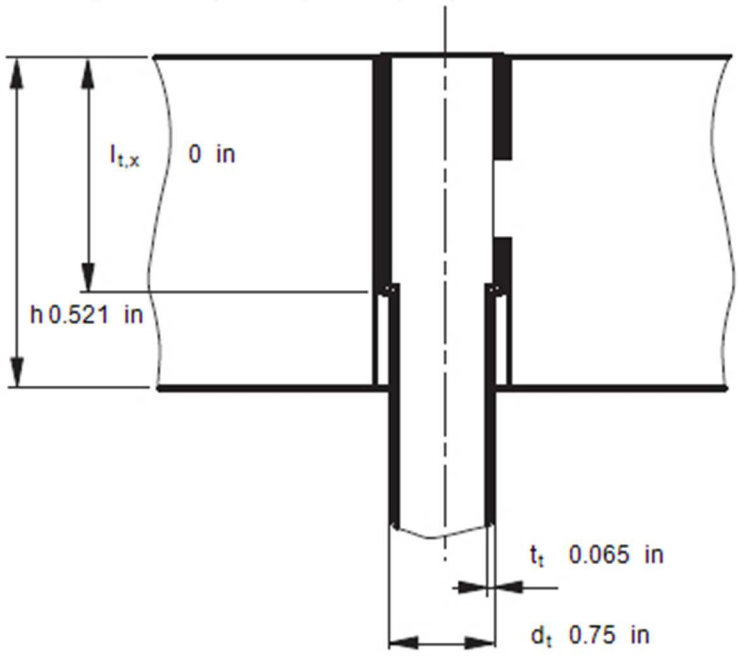
Safety at 20°C (or test) S_{fp}

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

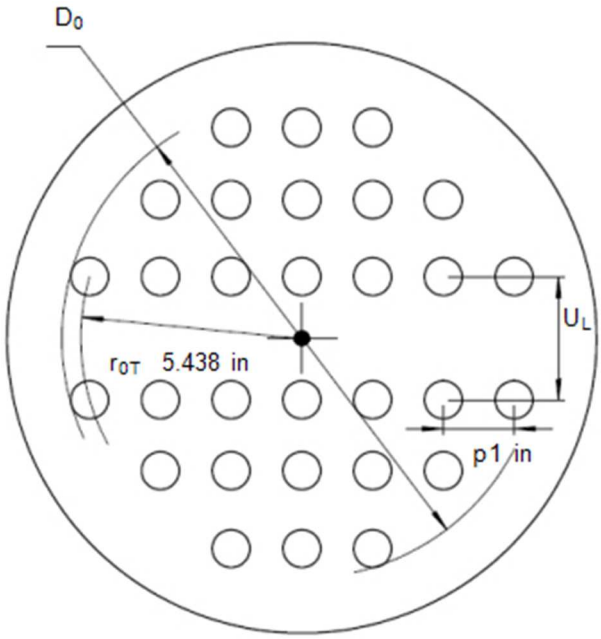
Bolt area in² :

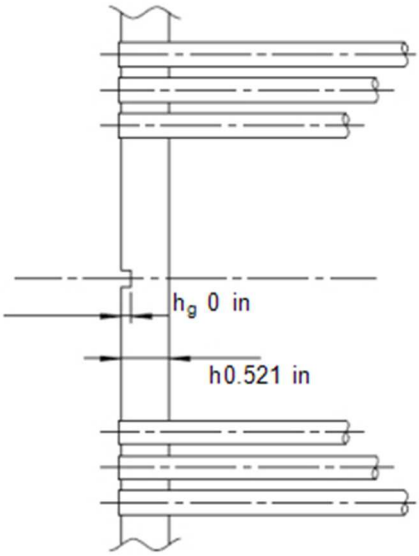
Additional specifications for geometry and loading
Tubesheet

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



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





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

Results acc. to UHX-12

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	App.2-5	W_m	**0**	lbf
Channel thickness without allowances		t_c	**0.313**	in
Shell thickness without allowances		t_s	**0.18**	in
Inside diameter of channel, corroded (Type ade)		D_c	**12.31**	in
Inside diameter of shell, corroded (Type abcd)		D_s	**12.39**	in
Recommended initial tubesheet thickness	UHX-12.4	h_{in}	**0.1206**	in
Tubesheet thickness without allowances > hin		h	**0.521**	in

Step 1 acc. to UHX 12.5

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

Step 2

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

Step 3

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

Step 4

Coefficient for shell pressure, Type abc	δ_S	**0.0258**	mm^3/N
Coefficient for moment of shell	ω_S	**0.491**	in²
Coefficient for channel pressure, Type aef	δ_c	**0.01466**	mm^3/N
Coefficient for moment of channel	ω_C	**0.7559**	in²

Step 5

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

Step 6

Rim moment	M*	**-49.62**	lbf

Step 7

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

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **35973** psi < **36143** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **3347** psi ≤ **10653** psi = $MIN[0.8\sigma_B ; 0.533\ S_y]$

Strength condition satisfied

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

σ_S =	**17750** psi	<	**27107** psi	= 1.5 · σ_{all}		
$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ =	**-169.6** psi	+	**-17580** psi			
σ_C =	**26621** psi	<	**27107** psi	= 1.5 · σ_{all}		
$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ =	**1343** psi	+	**25278** psi			
Shell length, uniform thickness > l_{Sm} = 0					or	**2.688** in
Channel length, uniform thickness > l_{Cm} = 0					or	**3.534** in

Strength condition acc. to UHX-12.5.10 satisfied

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

Geometric conditions:

valid

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

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

Allowable primary and secondary stress in the shell acc. to UG-23(e):
S_{PSs} = 3·σ_{all} (a) or 2·Yield strength (b) for operation
54215 psi = 3· **18072** psi or 2· 19986 psi
(b) under the condition: σ_{all} not in the creep range
T= **500** °F < 32 °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

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

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

(estimation, deleted Add.2009)

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

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

UHX-12.5.1 Step 1

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

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

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

UHX-12.5.2 Step 2

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

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

UHX-12.5.3 Step 3

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

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

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

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

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

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

UHX-12.5.4 Step 4

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

UHX-12.5.5 Step 5

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

UHX-12.5.6 Step 6

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

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

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

UHX-12.5.6 acc. UHX-12.6

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

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

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

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

τ		**or**	**τ acc. UHX12.6**		**≤ MIN[0.8σ_B ; 0.533 S_y]**	
τ =	**3347** psi	or	**3347** psi		≤	**10653** psi

Strength condition satisfied

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

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

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

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

Strength condition acc. to UHX-12.5.10 satisfied

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

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

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

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

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

Analogously for the channel:

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

Example 4.18.2 - U Tubesheet Exchanger , Configuration d

Step 1

		LV Soft				ASME		Diff [%]
Equivalent diameter	D_0	427,050	mm	16,813	in	16,813	in	**0,00%**
Basic ligamnet efficient for shear	μ	0,167		0,167	in	0,167		**0,20%**
Effective ligament efficiency for shear	h'_g	0,000	mm	0,000	in	0,000		**0,00%**

Step 2

		LV Soft				ASME		Diff [%]
Ratio Ds/D0	ρ_S	1,130		1,130		1,130		**0,01%**
Ratio Dc/D0	ρ_C	1,130		1,130		1,130		**0,01%**
Tubesheet rim moment	M_{TS}	-3491,661	N	-784,957	lbf	-785,000		**-0,01%**

Step 3

		LV Soft				ASME		Diff [%]
Effective mod. Elasticity tubesheet	**E***	51735,66		7,50E+06		7,50E+06		**0,05%**
Effective Poisson's ratio tubesheet	**v***	0,36		3,58E-01		3,58E-01		**0,12%**
Effective tube pitch	**p***	20,45	mm	8,05E-01	in	8,05E-01		**0,03%**
Effective ligament	**μ***	0,28		2,80E-01		2,80E-01		**0,06%**
Effective tube hole diameter	**d***	14,73	mm	5,80E-01	in	5,80E-01		**0,01%**

Step 5

		LV Soft	ASME	Diff [%]
Diameter ration A/D0	**K**	1,19E+00	1,19E+00	**0,00%**
Coefficient	**F**	4,20E-01	4,20E-01	**0,10%**

Step 6

		LV Soft		ASME		Diff [%]
Rim moment	**M***	-3491,66 N	-7,85E+02 lb/in	-7,85E+02 lb/in		**-0,01%**

Step 7

		LV Soft		ASME		Diff [%]
Bending moment at periphery	M_P	-713,50 N	-1,60E+02 lb/in	-1,60E+02 lb/in		**-0,25%**
Moment at the tubesheet	M_0	-10608,53 N	-2,38E+03 lb/in	-2,38E+03 lb/in		**-0,21%**

Step 8

		LV Soft		ASME		Diff [%]
Bending stress	**σ**	-215,19 N	-3,12E+04 psi	-3,12E+04 psi		**-0,04%**
Bending stress	$2\sigma_B$	216,00 N	3,13E+04 psi	3,14E+04 psi		**0,23%**

Step 9

		LV Soft		ASME		Diff [%]
Shear stress	**τ**	20,38 N	2,96E+03 psi	2,96E+03 psi		**0,15%**
Shear stress (Min 0,8σB; 0,533Sy)		86,40 N	1,25E+04 psi	1,26E+04 psi		**0,55%**

E.4.18.2 - U-Tubesheets - ASME BPVC VIII-1, UHX-12: 2021

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

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

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	300	°F	300	°F	300	°F		°F
Thickness	**1.405**	in		in	0.065	in		in
Outside diameter	20	in		in	0.625	in		in
Strength	15664	psi		psi	9993	psi		psi
Safety fac.	1				1			
Modulus of elasticity	2.829e+7	psi		psi	1.538e+7	psi		psi
Allow. c_1	0	in		in	0	in		in
Corr.all. c_2	0.125	in		in	0	in		in
Poisson's ratio		v	0.3				0.3	
Therm.exp.	6.885	1E-6/°F		1E-6/°F	9.995	1E-6/°F		1E-6/°F
Yield str.	26561	psi		psi	0	psi		psi
Limit temperature	32	°F		°F	32	°F		°F
All.Stress	**15664**	psi	**0**	psi	**9993**	psi	**0**	psi
Pr.+sec.st	**53122**	psi	**0**	psi	**29979**	psi	**0**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	26759	psi	0	psi	13053	psi	0	psi
Safety fac.	1				1			
Modulus of elasticity	2.935e+7	psi		psi	1.598e+7	psi		psi
Yield str.	29733	psi		psi	14504	psi		psi
Tensile str.	55114	psi		psi	44961	psi		psi

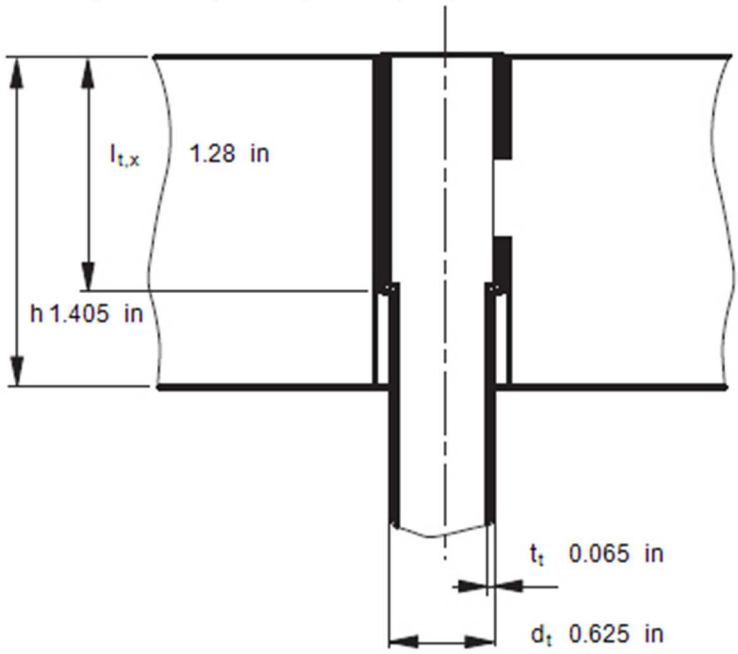
Mean contact diameter tubesheet-flange (Type cf)	G_1		in
Bolt circle diameter (Type bcdef)	C	21.65	in
Number of bolts	n		
Bolt root diameter	d_B		in
Total bolt area	A_b		in²
Bolt material	K50100-SA-193-B5-Class:-Size:<=100		
Strength for operation	K_s	20015	psi
Strength at 20°C (or test)	K_{sp}	20015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

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

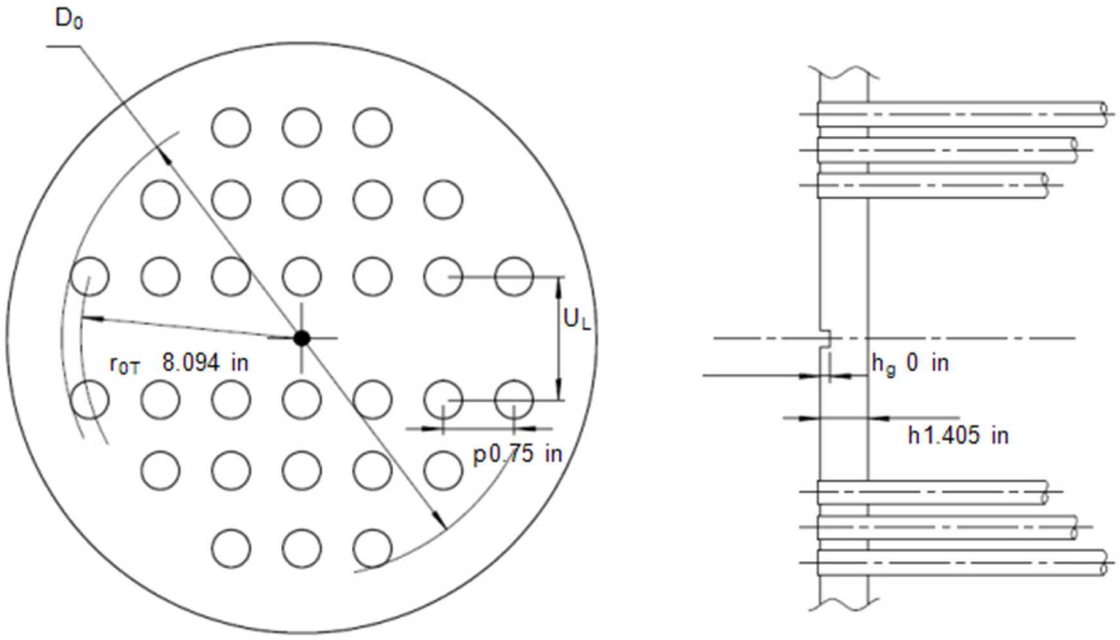
Bolt area in² :

Additional specifications for geometry and loading
Tubesheet

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



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



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

Results acc. to UHX-12

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	App.2-5	W_m	162000	lbf
Channel thickness without allowances		t_c		in
Shell thickness without allowances		t_s		in
Inside diameter of channel, corroded (Type ade)		D_c		in
Inside diameter of shell, corroded (Type abcd)		D_s		in
Recommended initial tubesheet thickness	UHX-12.4	h_{in}	**0.3019**	in
Tubesheet thickness without allowances > hin		h	1.28	in

Step 1 acc. to UHX 12.5

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

Step 2

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

Step 3

Effective mod. elasticity tubesheet	UHX-11.2, 11.3	E*	**7503585**	psi
Effective Poisson's ratio of tubesheet		v*	**0.3576**	
Effective tube pitch		p*	**0.8052**	in
Effective ligament efficiency for bending		μ*	**0.2798**	
Effective tube hole diameter		d*	**0.5799**	in

Step 4

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

Step 5

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

Step 6

Rim moment		M*	**-785**	lbf

Step 7

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

Step 8

Strength condition for the bending stress in the tubesheet:

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

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **2955** psi ≤ **12531** psi = $MIN[0.8\sigma_B ; 0.533\ S_y]$

Strength condition satisfied

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

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

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

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

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

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

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

UHX-12.5.10 not required for configuration d

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

Geometric conditions:

valid

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

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

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

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

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

(estimation, deleted Add.2009)

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

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

UHX-12.5.1 Step 1

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

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

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

UHX-12.5.2 Step 2

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

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

UHX-12.5.3 Step 3

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

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

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

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

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

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

UHX-12.5.4 Step 4

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

UHX-12.5.5 Step 5

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

UHX-12.5.6 Step 6

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

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

UHX-12.5.6 acc. UHX-12.6

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

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

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

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

	τ		**or**	**τ acc. UHX12.6**		**≤ MIN[0.8σ_B ; 0.533 S_y]**	
τ =	**2955**	psi	or	**2955**	psi	≤ **12531**	psi

Strength condition satisfied

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

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

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

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

UHX-12.5.10 not required for configuration d

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

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

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

σ_S = **0** psi ≤ **0** psi = S_{PSs}

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

Analogously for the channel:

σ_C = **0** psi ≤ **0** psi = S_{PSc}

Example 4.18.4 - U Tubesheet Exchanger , Configuration e

Step 1

		LV Soft				ASME		Diff [%]
Equivalent diameter	D_0	666,750	mm	26,250	in	26,250	in	**0,00%**
Basic ligamnet efficient	μ	0,250		0,250	in	0,250		**0,00%**
Effective ligament efficiency	h'_g	0,000	mm	0,000	in	0,000		**0,00%**

Step 2

		LV Soft				ASME	Diff [%]
Ratio Ds/D0	ρ_S	1,233		1,233		1,230	**0,27%**
Ratio Dc/D0	ρ_C	1,181		1,181		1,180	**0,08%**
Tubesheet rim moment	M_{TS}	73250,375	N	16467,344	lbf	16500,000	**0,20%**

Step 3

		LV Soft				ASME	Diff [%]
Effective mod. Elasticity	**E***	84616,73		1,23E+07		1,22E+07	**0,60%**
Effective Poisson's ratio	**ν***	0,32		3,18E-01		3,18E-01	**0,03%**
Effective tube pitch	**p***	26,29	mm	1,04E+00	in	1,04E+00	**0,47%**
Effective ligament efficient	**μ***	0,39		3,85E-01		3,85E-01	**0,13%**
Effective tube hole diameter	**d***	16,16	mm	6,36E-01	in	6,36E-01	**0,01%**

Step 4

		LV Soft				ASME		Diff [%]
Coefficient for shell pressure	δ_S		mm^3/N		in^3/lb		in^3/lb	
Coefficient for moment of shell	ω_S	0,00	mm^2	0,00E+00	in^2		in^2	**0,00%**
Coefficient for channel pressure	δ_C	0,04	mm^3/N	1,17E-05	in^3/lb	1,18E-05	in^3/lb	**0,26%**
Coefficient for moment	ω_C	4524,31	mm^2	7,01E+00	in^2	7,01E+00	in^2	**0,04%**

Step 5

		LV Soft	ASME	Diff [%]
Diameter ration A/D0	**K**	1,42E+00	1,42E+00	**0,07%**
Coefficient	**F**	9,64E-01	9,64E-01	**0,05%**

Step 6

		LV Soft			ASME		Diff [%]
Rim moment	**M***	119692,09	N	2,69E+04 lb/in	2,69E+04	lb/in	**0,03%**

Step 7

		LV Soft			ASME		Diff [%]
Bending moment at periphery	**M_P**	30361,33	N	6,83E+03 lb/in	6,83E+03	lb/in	**0,07%**
Moment at the tubesheet center	**M_0**	133648,30	N	3,00E+04 lb/in	3,00E+04	lb/in	**0,15%**

Step 8

		LV Soft			ASME		Diff [%]
Bending stress	**σ**	263,21	N	3,82E+04 psi	3,82E+04	psi	**0,07%**
Bending stress	**$2\sigma_B$**	275,79	N	4,00E+04 psi	4,00E+04	psi	**0,00%**

Step 9

		LV Soft			ASME		Diff [%]
Shear stress	**τ**	33,61	N	4,88E+03 psi	4,88E+03	psi	**0,10%**
Shear stress (Min 0,8σB; 0,533Sy)		110,32	N	1,60E+04 psi	1,60E+04	psi	**0,00%**

Step 10

	LV Soft			ASME		Diff [%]
σ_S	0,00	N	0,00E+00 psi		psi	**0,00%**
$1{,}5.\sigma_{all}$	0,00	N	0,00E+00 psi		psi	**0,00%**
$\sigma_{S,m}$	0,00	N	0,00E+00 psi		psi	**0,00%**
$\sigma_{S,b}$	0,00	N	0,00E+00 psi		psi	**0,00%**
σ_C	392,69	N	5,70E+04 psi	5,70E+04	psi	**0,08%**
$1{,}5.\sigma_{all}$	206,84	N	3,00E+04 psi	3,00E+04	psi	**0,00%**
$\sigma_{c,m}$	0,00	N	0,00E+00 psi	0,00E+00	psi	**0,00%**
$\sigma_{c,b}$	-392,69	N	-5,70E+04 psi	-5,70E+04	psi	**0,08%**

E.4.18.4 - U-Tubesheets - ASME BPVC VIII-1, UHX-12: 2021

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

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

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	400	°F		°F	400	°F	400	°F
Thickness	3.625	in		in	0.085	in	0.625	in
Outside diameter	37.25	in		in	0.75	in	32.25	in
Strength	20000	psi		psi	13401	psi	20000	psi
Safety fac.	1				1		1	
Modulus of elasticity	2.781e+7	psi		psi	2.781e+7	psi	2.781e+7	psi
Allow. c_1	0	in		in	0	in	0	in
Corr.all. c_2	0.125	in		in	0	in	0	in
Poisson's ratio			v 0.3				0.3	
Therm.exp.	7.07	1E-6/°F		1E-6/°F	7.07	1E-6/°F	7.07	1E-6/°F
Yield str.	32530	psi		psi	22258	psi	32530	psi
Limit temperature	32	°F		°F	32	°F	32	°F
All.Stress	**20000**	psi	0	psi	**13401**	psi	**20000**	psi
Pr.+sec.st	**60000**	psi	0	psi	**40204**	psi	**60000**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	33939	psi	0	psi	23496	psi	33939	psi
Safety fac.	1				1		1	
Modulus of elasticity	2.935e+7	psi		psi	2.935e+7	psi	2.935e+7	psi
Yield str.	37710	psi		psi	26107	psi	37710	psi
Tensile str.	70343	psi		psi	47137	psi	70343	psi

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

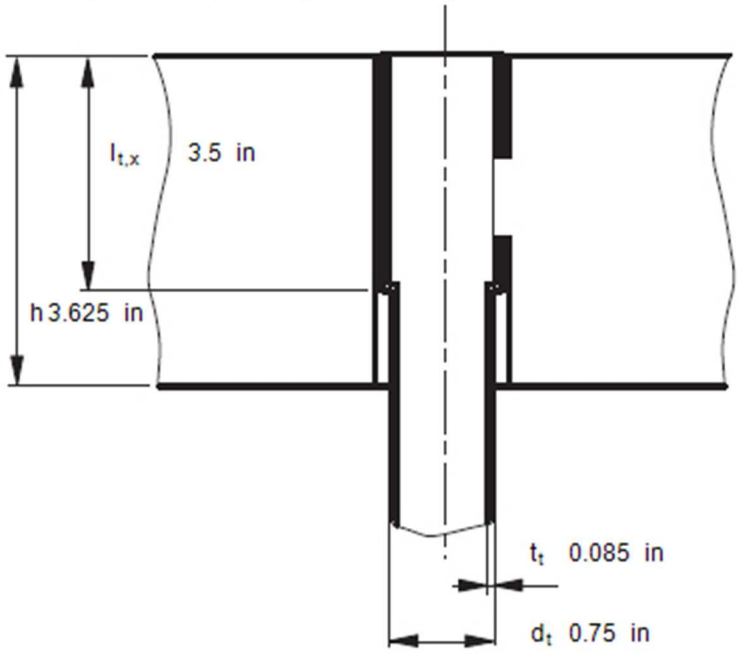
Safety for operation	S_f		
Safety at 20°C (or test)	S_{fp}		

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

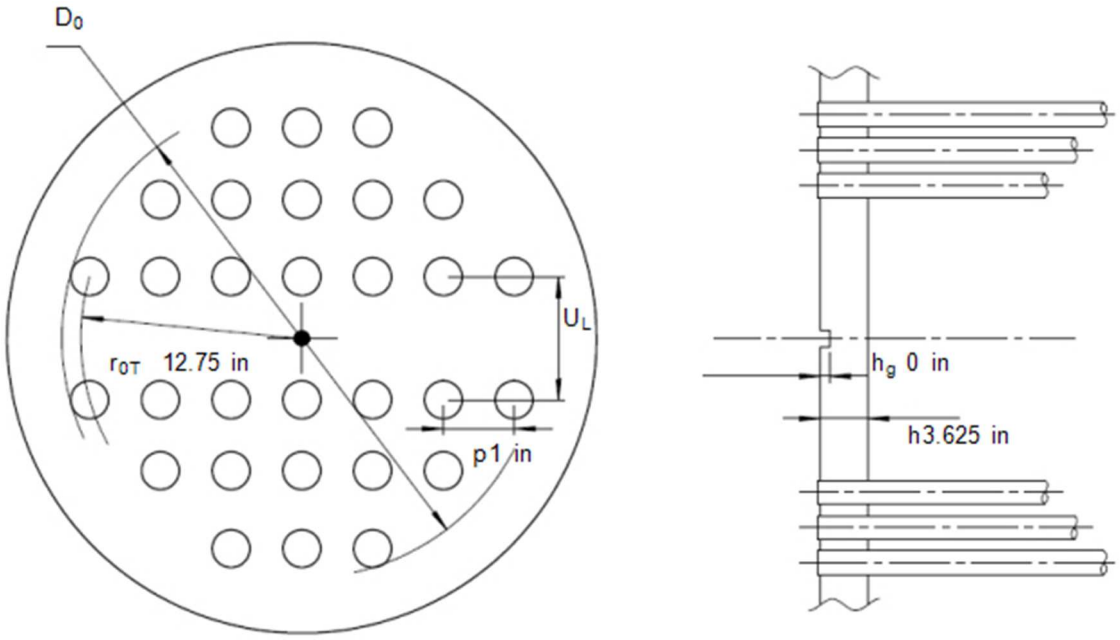
Bolt area in² :

Additional specifications for geometry and loading
Tubesheet

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



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



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

Results acc. to UHX-12

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	App.2-5	W_m	656000	lbf
Channel thickness without allowances		t_c	**0.625**	in
Shell thickness without allowances		t_s		in
Inside diameter of channel, corroded (Type ade)		D_c	**31**	in
Recommended initial tubesheet thickness	UHX-12.4	h_{in}	**1.066**	in
Tubesheet thickness without allowances > hin		h	**3.5**	in

Step 1 acc. to UHX 12.5

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

Step 2

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

Step 3

Effective mod. elasticity tubesheet	UHX-11.2, 11.3	E*	**1.227e+7**	psi
Effective Poisson's ratio of tubesheet		v*	**0.3179**	
Effective tube pitch		p*	**1.035**	in
Effective ligament efficiency for bending		μ*	**0.3855**	
Effective tube hole diameter		d*	**0.6361**	in

Step 4

Coefficient for moment of shell	ω_S	**0**	in²
Coefficient for channel pressure, Type aef	δ_c	**0.04329**	mm^3/N
Coefficient for moment of channel	ω_C	**7.013**	in²

Step 5

Diameter ratio = A/D0	K	**1.419**	
Coefficient	F	**0.9645**	

Step 6

Rim moment	M*	**26908**	lbf

Step 7

Bending moment at periphery	M_p	**6826**	lbf
Moment at the tubesheet center	M_0	**30045**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **38175** psi < **40000** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **4875** psi ≤ **16000** psi = $MIN[0.8\sigma_B ; 0.533\ S_y]$

Strength condition satisfied

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

σ_S =	**0** psi	<	**0** psi	= 1.5 · σ_{all}	
$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ =	**0** psi	+	**0** psi		
σ_C =	**56954** psi	<	**30000** psi	= 1.5 · σ_{all}	
$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ =	**0** psi	+	**-56954** psi		
Shell length, uniform thickness > l_{Sm} = 0				or	in
Channel length, uniform thickness > l_{Cm} = 0				or	**7.923** in

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

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

Geometric conditions:

valid

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

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

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

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

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

(estimation, deleted Add.2009)

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

$$\frac{1}{(4 \cdot 0.25)} \cdot \frac{666.8\ \text{mm}}{(0.8 \cdot 137.9\ \text{N/mm}^2)} \cdot \left| 4.482\ \text{N/mm}^2 - 4.482\ \text{N/mm}^2 \right| = 27.09\ \text{mm}$$

UHX-12.5.1 Step 1

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

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

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

UHX-12.5.2 Step 2

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

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

UHX-12.5.3 Step 3

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

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

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

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

$$d2^*=d_T-2\cdot t_T\cdot\frac{E_T}{E_B}\cdot\frac{\sigma_T}{\sigma_B}\cdot\rho=19.05\text{ mm}-2\cdot 2.159\text{ mm}\cdot\frac{191733\text{ N/mm²}}{191733\text{ N/mm²}}\cdot\frac{92.4\text{ N/mm²}}{137.9\text{ N/mm²}}\cdot 1=d2^*$$

$$\mu^*=\frac{(p^*-d^*)}{d^*}=\frac{(26.29\text{ mm}-16.16\text{ mm})}{16.16\text{ mm}}=0.3855$$

UHX-12.5.4 Step 4

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

UHX-12.5.5 Step 5

$$F=\frac{(1-v^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.3179)}{84617\text{ N/mm²}}\cdot(0\text{ N/mm²}+52543\text{ N/mm²}+191733\text{ N/mm²}\cdot\ln(1.419))=0.9645$$

UHX-12.5.6 Step 6

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

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

UHX-12.5.6 acc. UHX-12.6

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

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

σ			**or**	**σ acc. UHX12.6**		**< 2· σ_B**	
σ =	**38175**	psi	or	**45447**	psi	< 2·	**20000** psi

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

τ			**or**	**τ acc. UHX12.6**		**≤ MIN[0.8σ_B ; 0.533 S_y]**	
τ =	**4875**	psi	or	**4875**	psi	≤	**16000** psi

Strength condition satisfied

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

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

in MPa:	**σ_m**		**σ_b**		**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**0**	+	**0**	= **0**	< 1.5·	0	or	0
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**0**	+	**-392.7**	= **392.7**	< 1.5·	**137.9**	or	**413.7**

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

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

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

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

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

σ_S = **0** psi ≤ 0 psi = S_{PSs}

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

Analogously for the channel:

σ_C = **56954** psi ≤ **60000** psi = S_{PSc}