



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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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



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Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

Strength Calculation Software Program System ATLAS Version **10.0.92**
 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

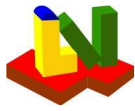
		LV Soft				ASME		Diff [%]
Equivalent diameter	D_0	295,300	mm	1,16E+01	in	1,16E+01	in	0,00%
Basic ligament efficient	μ	0,250		2,50E-01	in	2,50E-01		0,00%
Effective ligament efficiency	h'_g	0,000	mm	0,00E+00	in	0,00E+00	in	0,00%

Step 2

		LV Soft				ASME		Diff [%]
Ratio D_s/D_0	ρ_s	1,066		1,07E+00		1,07E+00		0,40%
Ratio D_c/D_0	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 [%]
		79427,4						
Effective mod. Elasticity	E^*	8	Mpa	1,15E+07	psi	1,15E+07	psi	0,17%
Effective Poisson's ratio	ν^*	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%



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Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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	M₀	-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	2σ_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 0,8 σ_B ; 0,533Sy)		73,45	N	1,07E+04	psi	1,07E+04 psi	0,00%



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Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

Step 10

		LV Soft				ASME		Diff [%]
	σ_s	122,38	N	1,78E+04	psi	1,77E+04	psi	0,28%
	1,5.σ_{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.σ_{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%



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Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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

Tubesheet integral with shell and channel

Channel type (1=Cylinder, 2=Hemispherical)

Internal operating pressure shell side

Internal operating pressure tube side

Internal test pressure shell side

Internal test pressure tube side

Load case (1=Operation, 2+3=Test at 20°C, 4=other)

load case: operation

Calculation case UHX12.4(a) (1: Ps=0, 2: Pt=0, 3:Differ.)

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	Tubesheet	Shell	Tubes	Channel
temperature°C				
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				
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	in ²
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	



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Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

Safety at 20°C (or test)

S_{fp}

Gasket

Contact outside diameter
Contact inside diameter
Basic seating width
Gasket factor (Table 2-5.1)
Gasket seating pressure
Diameter of gasket force

Shell
Type d,e,f
 G_a in
 G_i in
 b_0 in
 m
 Y psi
 G in

Channel

Type b,c,d

in
in
in
psi
in

Results acc. UHX-9

Effective seating width
Initial gasket force
Gasket operation force
Total req. bolt root area
Flange thickness

Shell
 b in
 W 0 lbf
 W 0 lbf
 A_m 0 in²
 h_r 0 in

Channel

in
0 lbf
0 lbf
0 in²
0 in

Bolt area

in² :

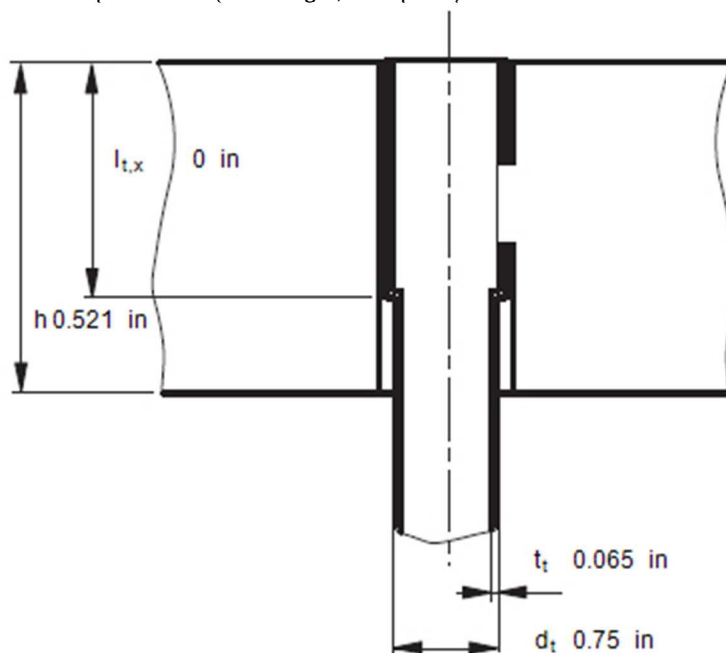
Additional specifications for geometry and loading

Tubesheet

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

N

1
2



Expanded length of tube in tubesheet
Radius to outermost tube hole center
Perimeter of the outermost tubes
Total area enclosed by C_p
Tube hole pitch (Center distance)

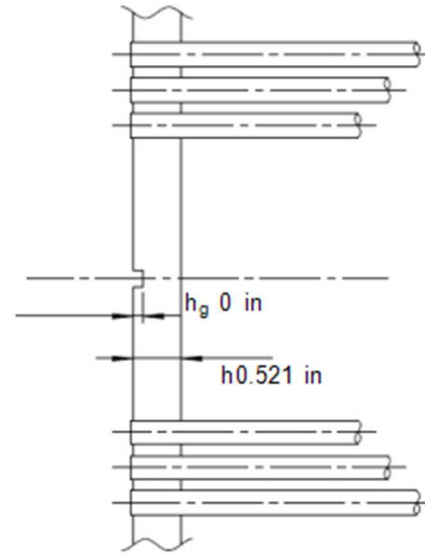
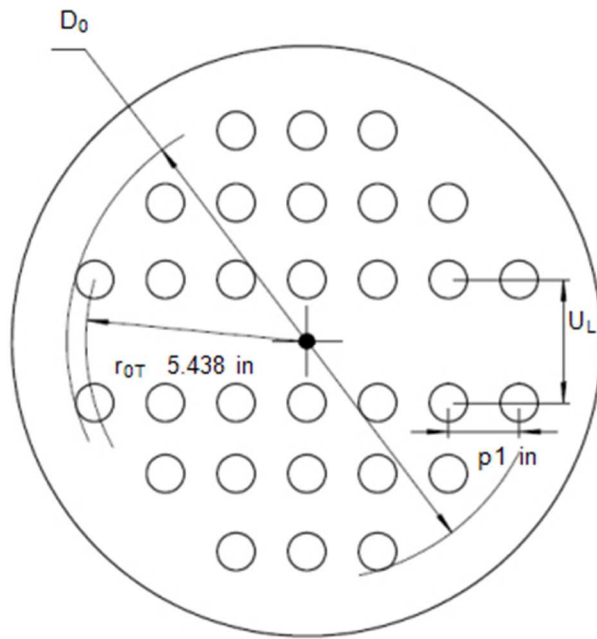
UHX-11.1a
UHX-12.2
UHX-12.2

$l_{t,x}$ 0 in
 r_{0T} 5.438 in
 C_p in
 A_p in²
 p 1 in



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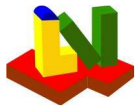
Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021



Untubed area $U_L \cdot LL_1 + U_L \cdot LL_2 \dots$
 Depth of pass partition groove
 Length ratio of tube expansion l_{tx}/h

UHX-11.2

A_L 26.17 in²
 h_g 0 in
 ρ 0



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Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

Results acc. to UHX-12

Gasket seating force =	App.2-5	W_m	0 lbf
$0.5(A_m+Ab) \cdot K_{sp}/S_{sp}$			
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 > h_{in}

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 D_s/D_0 (Type abc) or G_s/D_0 (Type def)	ρ_s	1.066
Ratio D_c/D_0 (Type aef) or G_c/D_0 (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	ν^*	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 in ²
Coefficient for channel pressure, Type aef	δ_c	0.01466 mm ³ /N
Coefficient for moment of channel	ω_c	0.7559 in ²

Step 5

Diameter ratio = A/D_0	K	1.113
Coefficient	F	9.406

Step 6

Rim moment	M^*	-49.62 lbf
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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:

$$\sigma = 35973 \text{ psi} < 36143 \text{ psi} = 2 \cdot \sigma_B$$

Step 9

Strength condition for the shear stress in the tubesheet:

$$\tau = 3347 \text{ psi} \leq 10653 \text{ psi} = \text{MIN}[0.8\sigma_B ; 0.533 S_y]$$

Strength condition satisfied

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

$\sigma_S = 17750 \text{ psi}$	$<$	27107 psi	$= 1.5 \cdot \sigma_{all}$
$\sigma_S = \sigma_{Sm} + \sigma_{Sb} = -169.6 \text{ psi}$	$+$	-17580 psi	
$\sigma_C = 26621 \text{ psi}$	$<$	27107 psi	$= 1.5 \cdot \sigma_{all}$
$\sigma_C = \sigma_{Cm} + \sigma_{Cb} = 1343 \text{ psi}$	$+$	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):

$$S_{PS} = 3 \cdot \sigma_{all} \text{ (a) or } 2 \cdot \text{Yield strength (b) for operation}$$

$$54215 \text{ psi} = 3 \cdot 18072 \text{ psi} \text{ or } 2 \cdot 19986 \text{ psi}$$

(b) under the condition: σ_{all} not in the creep range

$$T = 500 \text{ }^{\circ}\text{F} < 32 \text{ }^{\circ}\text{F}$$

and: Yield strength < 0.7 · Tensile strength at room temperature (20°C)

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

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

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot |p_T - p_S| = \quad \text{(estimation, deleted Add.2009)}$$

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

UHX-12.5.1 Step 1

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

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

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

UHX-12.5.2 Step 2

$$M_{TS120} = \frac{D_0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho_C^2 + 1) \cdot P_t \right] =$$

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

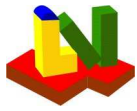
UHX-12.5.3 Step 3

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

$$\rho^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{25.4 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 16884 \text{ mm}^2}{\pi \cdot (295.3 \text{ mm})^2}}} = 29.26 \text{ mm}$$

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

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



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Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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

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

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

$$F = \frac{(1 - \nu^*)}{E^*} \cdot (\lambda_S + \lambda_C + E^* \cdot \ln(K)) = \frac{(1 - 0.2539)}{79427 \text{ N/mm}^2} \cdot (221270 \text{ N/mm}^2 + 760973 \text{ N/mm}^2 + 178400 \text{ N/mm}^2 \cdot \ln(1.113)) = 9.406$$

UHX-12.5.6 Step 6

$$M^* = M_{TS} + \omega_C \cdot P_C - \omega_S \cdot P_S + M_{add} = -713.3 \text{ N} + 487.7 \text{ mm}^2 \cdot 0.9653 \text{ N/mm}^2 - 316.8 \text{ mm}^2 \cdot -0.06895 \text{ N/mm}^2 + 0 \text{ N} = -220.7 \text{ N}$$

$$M_{add} = 0 = 0 \text{ lbf}$$

UHX-12.5.6 acc. UHX-12.6

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

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

σ	35973 psi	or	σ acc. UHX12.6	$< 2 \cdot \sigma_B$	18072 psi
$\sigma =$		or	-67799 psi	$< 2 \cdot$	

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

τ	3347 psi	or	τ acc. UHX12.6	$\leq \text{MIN}[0.8\sigma_B ; 0.533 S_y]$	10653 psi
$\tau =$		or	3347 psi	\leq	

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	$< 1.5 \cdot \sigma_{all}$	or	$S_{PS}^*)$
$\sigma_S = \sigma_{Sm} + \sigma_{Sb} =$	-1.169 +	-121.2 =	122.4 $< 1.5 \cdot$	124.6 or	373.8
$\sigma_C = \sigma_{Cm} + \sigma_{Cb} =$	9.259 +	174.3 =	183.5 $< 1.5 \cdot$	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:

Modulus of elasticity	elastic	N	(Y=Yes, N=No)
Shell	2.587e+7 psi	Option 3	
Channel	2.587e+7 psi		

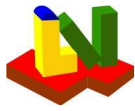
Acc. to option 3, the modulus of elasticity of the shell E_S is replaced by $E_S \cdot \sqrt{(1.5 \cdot \sigma_{allS} / \sigma_S)}$, under the conditions:

$\sigma_S =$	17750 psi	\leq	54215 psi	$= S_{PSs}$
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with the allowable primary+secondary stress S_{PSs} , if the allowable stress σ_{allS} is outside of the creep range!

Analogously for the channel:

$\sigma_C =$	26621 psi	\leq	54215 psi	$= S_{PSc}$
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ASME BPVC VIII-1 2021
Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021



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 ligament 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

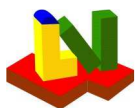
		LV Soft		ASME	Diff [%]
Ratio D_s/D_0	ρ_s	1,130	1,130	1,130	0,01%
Ratio D_c/D_0	ρ_c	1,130	1,130	1,130	0,01%
Tubesheet rim moment	M_{TS}	-3491,661 N	-784,957 lbf	-785,000	-0,01%

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	ν^*	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/D_0	K		1,19E+00	1,19E+00	0,00%
Coefficient	F		4,20E-01	4,20E-01	0,10%



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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 0,8 σ_B ; 0,533 S_y)		86,40 N	1,25E+04 psi	1,26E+04 psi	0,55%



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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

Tubesheet gasketed with shell and channel

Channel type (1=Cylinder, 2=Hemispherical)

Internal operating pressure shell side

Internal operating pressure tube side

Internal test pressure shell side

Internal test pressure tube side

Load case (1=Operation, 2+3=Test at 20°C, 4=other)

load case: operation

Calculation case UHX12.4(a) (1: Ps=0, 2: Pt=0, 3:Differ.)

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	Tubesheet	Shell	Tubes	Channel
temperature°C				
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		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	in ²
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



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

Gasket

Contact outside diameter
Contact inside diameter
Basic seating width
Gasket factor (Table 2-5.1)
Gasket seating pressure
Diameter of gasket force

G_a in
 G_i in
 b_0 in
 m
 Y psi
 G 19 in

Channel

Type b,c,d

in
in
in
psi
19 in

Results acc. UHX-9

Effective seating width
Initial gasket force
Gasket operation force
Total req. bolt root area
Flange thickness

Shell
 b in
 W 147000 lbf
 W 147000 lbf
 A_m **7.344** in²
 h_r in

Channel

in
162000 lbf
162000 lbf
8.094 in²
in

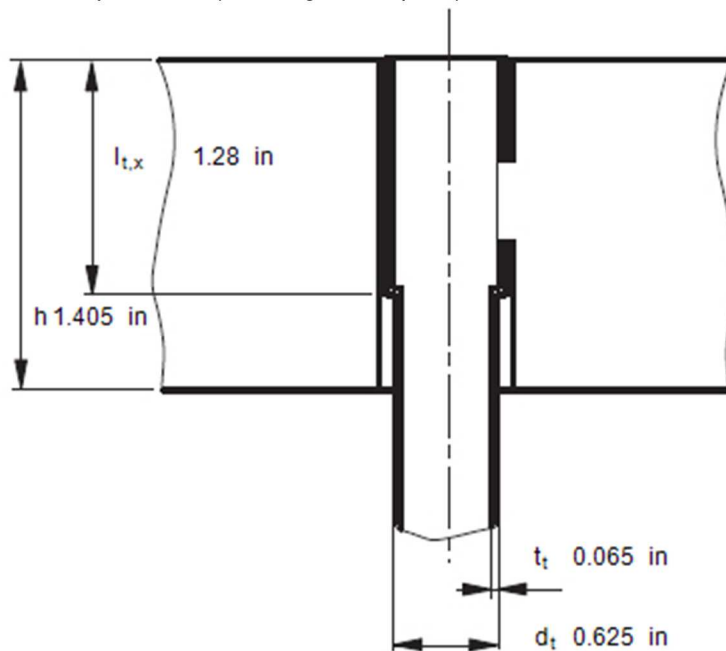
Bolt area in² :

Additional specifications for geometry and loading

Tubesheet

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

N
1
1



Expanded length of tube in tubesheet
Radius to outermost tube hole center
Perimeter of the outermost tubes
Total area enclosed by C_p
Tube hole pitch (Center distance)

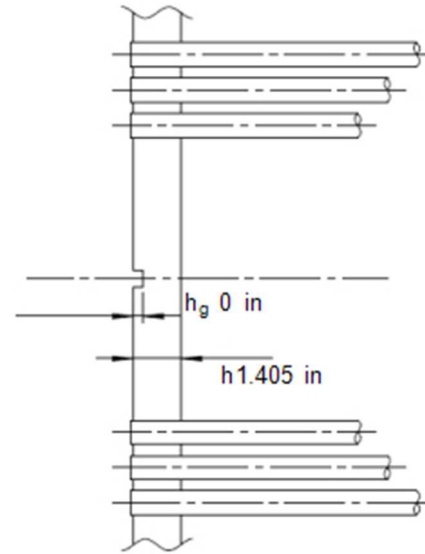
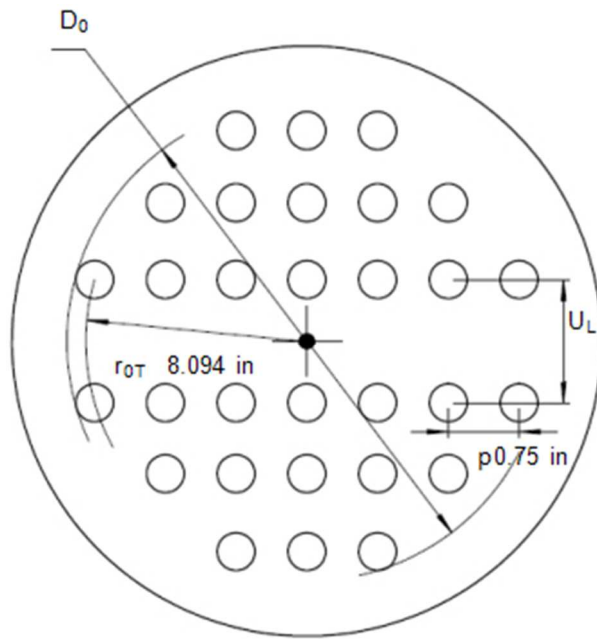
UHX-11.1a
UHX-12.2
UHX-12.2

$l_{t,x}$ **1.28** in
 r_{0T} 8.094 in
 C_p in
 A_p in²
 p 0.75 in



ASME BPVC VIII-1 2021

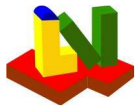
Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021



Untubed area $UL1 \cdot LL1 + UL2 \cdot LL2 \dots$
 Depth of pass partition groove
 Length ratio of tube expansion lt_x/h

UHX-11.2

A_L 29.42 in²
 h_g 0 in
 ρ 1



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

Results acc. to UHX-12

Gasket seating force =	App.2-5	W_m	162000 lbf
$0.5(A_m + A_b) \cdot K_{sp}/S_{sp}$			
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 > h_{in} 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 D_s/D_0 (Type abc) or G_s/D_0 (Type def)	ρ_s	1.13
Ratio D_c/D_0 (Type aef) or G_c/D_0 (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	ν^*	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 in ²
Coefficient for moment of channel	ω_c	0 in ²

Step 5

Diameter ratio = A/D_0	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:
 $\sigma = -31211$ psi < **31328** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:
 $\tau = 2955$ psi \leq **12531** psi = $\text{MIN}[0.8\sigma_B ; 0.533 S_y]$

Strength condition satisfied

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

$\sigma_S =$	0 psi	<	0 psi	= $1.5 \cdot \sigma_{all}$
$\sigma_S = \sigma_{Sm} + \sigma_{Sb} =$	0 psi	+	0 psi	
$\sigma_C =$	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):

$$S_{PSs} = 3 \cdot \sigma_{all} \text{ (a) or } 2 \cdot \text{Yield strength (b) for operation}$$

$$\mathbf{0} \text{ psi} = 3 \cdot \mathbf{0} \text{ psi} \text{ or } 2 \cdot \text{psi}$$

(b) under the condition: σ_{all} not in the creep range

$$T = \mathbf{300} \text{ }^{\circ}\text{F} < \text{ }^{\circ}\text{F}$$

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)

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

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

UHX-12.5.1 Step 1

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

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

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

UHX-12.5.2 Step 2

$$M_{TS120} = \frac{D_0^2}{16} \cdot [((\rho_s - 1)(\rho_s^2 + 1) \cdot P_s) - (\rho_c - 1)(\rho_c^2 + 1) \cdot P_t] =$$

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

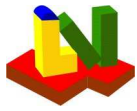
UHX-12.5.3 Step 3

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

$$\rho^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{19.05 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 18979 \text{ mm}^2}{\pi \cdot (427.1 \text{ mm})^2}}} = 20.45 \text{ mm}$$

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

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



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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

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

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

$$F = \frac{(1 - \nu^*)}{E^*} \cdot (\lambda_S + \lambda_C + E^* \cdot \ln(K)) = \frac{(1 - 0.3576)}{51736 \text{ N/mm}^2} \cdot (0 \text{ N/mm}^2 + 0 \text{ N/mm}^2 + 195067 \text{ N/mm}^2 \cdot \ln(1.19)) = 0.4204$$

UHX-12.5.6 Step 6

$$M^* = M_{TS} + \omega_C \cdot P_C - \omega_S \cdot P_S + M_{add} = -3492 \text{ N} + 0 \text{ mm}^2 \cdot 0.9308 \text{ N/mm}^2 - 0 \text{ mm}^2 \cdot -0.1034 \text{ N/mm}^2 + 0 \text{ N} = -3492 \text{ N}$$

$$M_{add} = (G_C - G_S) \cdot W_m / (2 \cdot \pi \cdot D_0) = 0 \text{ lbf}$$

UHX-12.5.6 acc. UHX-12.6

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

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

$$\sigma = -31211 \text{ psi} \quad \text{or} \quad \sigma \text{ acc. UHX12.6} < 2 \cdot \sigma_B < 2 \cdot 15664 \text{ psi}$$

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

$$\tau = 2955 \text{ psi} \quad \text{or} \quad \tau \text{ acc. UHX12.6} \leq \text{MIN}[0.8 \sigma_B ; 0.533 S_y] \leq 12531 \text{ psi}$$

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 $< 1.5 \cdot \sigma_{all}$ or $S_{PS}^*)$

$$\sigma_S = \sigma_{Sm} + \sigma_{Sb} = 0 + 0 = 0 < 1.5 \cdot 0 \text{ or } 0$$

$$\sigma_C = \sigma_{Cm} + \sigma_{Cb} = 0 + 0 = 0 < 1.5 \cdot 0 \text{ or } 0$$

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

UHX-12.5.10 not required for configuration d

Step 11: The modulus of elasticity is reduced:

Modulus of elasticity elastic N (Y=Yes, N=No) Option 3 psi psi

Shell psi psi

Channel psi psi

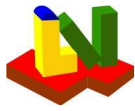
Acc. to option 3, the modulus of elasticity of the shell E_S is replaced by $E_S \cdot \sqrt{(1.5 \cdot \sigma_{allS} / \sigma_S)}$, under the conditions:

$$\sigma_S = 0 \text{ psi} \leq 0 \text{ psi} = S_{PSs}$$

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

Analogously for the channel:

$$\sigma_C = 0 \text{ psi} \leq 0 \text{ psi} = S_{PSc}$$



ASME BPVC VIII-1 2021
Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021



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 ligament 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 D_s/D_0	ρ_s	1,233		1,233		1,230	0,27%
Ratio D_c/D_0	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%



ASME BPVC VIII-1 2021
Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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	M₀	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%



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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

Tubesheet with flange, gasketed with shell, integral with channel

Channel type (1=Cylinder, 2=Hemispherical)

Internal operating pressure shell side

Internal operating pressure tube side

Internal test pressure shell side

Internal test pressure tube side

Load case (1=Operation, 2+3=Test at 20°C, 4=other)

load case: operation

Calculation case UHX12.4(a) (1: $P_s=0$, 2: $P_t=0$, 3:Differ.)

Shell side pressure acting ($P_t=0$)

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	Tubesheet	Shell	Tubes	Channel
temperature°C				
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		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	in ²
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



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

Safety for operation
Safety at 20°C (or test)

S_f
 S_{fp}

Gasket

Contact outside diameter
Contact inside diameter
Basic seating width
Gasket factor (Table 2-5.1)
Gasket seating pressure
Diameter of gasket force

G_a in
 G_i in
 b_0 in
 m
 Y psi
 G 32.38 in

Channel Type b,c,d

in
in
in
psi
in

Results acc. UHX-9

Effective seating width
Initial gasket force
Gasket operation force
Total req. bolt root area
Flange thickness

Shell
 b in
 W lbf
 W 656000 lbf
 A_m in²
 h_r in

Channel

in
0 lbf
0 lbf
0 in²
in

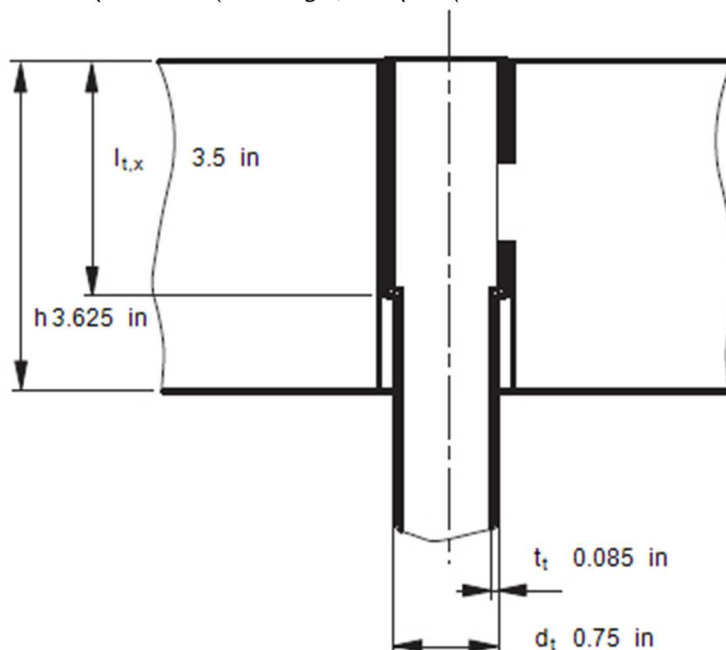
Bolt area in² :

Additional specifications for geometry and loading

Tubesheet

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

N
1
2



Expanded length of tube in tubesheet
Radius to outermost tube hole center
Perimeter of the outermost tubes
Total area enclosed by C_p
Tube hole pitch (Center distance)

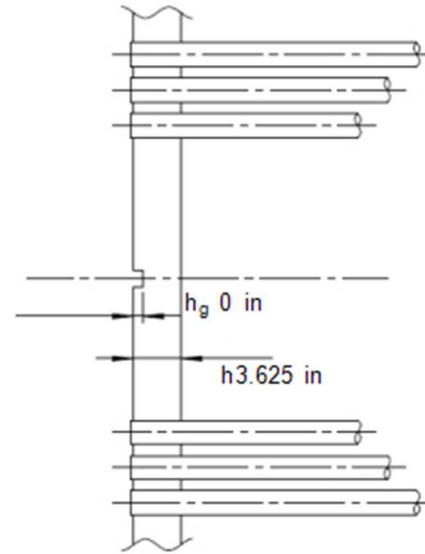
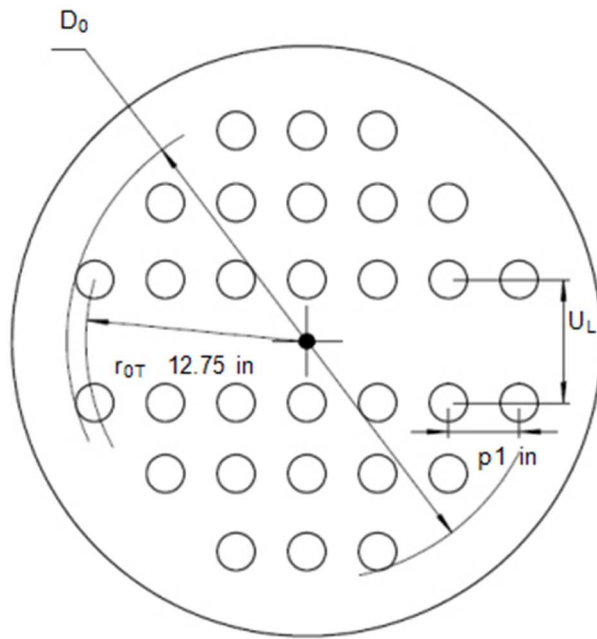
UHX-11.1a
UHX-12.2
UHX-12.2

$l_{t,x}$ 3.5 in
 r_{0T} 12.75 in
 C_p in
 A_p in²
 p 1 in



ASME BPVC VIII-1 2021

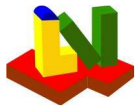
Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021



Untubed area $U_L \cdot LL_1 + U_L \cdot LL_2 \dots$
 Depth of pass partition groove
 Length ratio of tube expansion l_{tx}/h

UHX-11.2

A_L 36.09 in²
 h_g 0 in
 ρ 1



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

Results acc. to UHX-12

Gasket seating force =	App.2-5	W_m	656000 lbf
$0.5(A_m + A_b) \cdot K_{sp}/S_{sp}$			
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 > h_{in} 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 D_s/D_0 (Type abc) or G_s/D_0 (Type def)		ρ_s	1.233
Ratio D_c/D_0 (Type aef) or G_c/D_0 (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		ν^*	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 in ²
Coefficient for channel pressure, Type aef		δ_c	0.04329 mm ³ /N
Coefficient for moment of channel		ω_c	7.013 in ²

Step 5

Diameter ratio = A/D_0		K	1.419
Coefficient		F	0.9645

Step 6

Rim moment		M^*	26908 lbf
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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:
 $\sigma =$ **38175** psi < **40000** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:
 $\tau =$ **4875** psi \leq **16000** psi = $\text{MIN}[0.8\sigma_B ; 0.533 S_y]$

Strength condition satisfied

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

$\sigma_S =$	0 psi	<	0 psi	= $1.5 \cdot \sigma_{all}$
$\sigma_S = \sigma_{Sm} + \sigma_{Sb} =$	0 psi	+	0 psi	
$\sigma_C =$	56954 psi	<	30000 psi	= $1.5 \cdot \sigma_{all}$
$\sigma_C = \sigma_{Cm} + \sigma_{Cb} =$	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



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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):

$$S_{PSs} = 3 \cdot \sigma_{all} \text{ (a) or } 2 \cdot \text{Yield strength (b) for operation}$$

$$0 \text{ psi} = 3 \cdot 0 \text{ psi} \text{ or } 2 \cdot \text{psi}$$

(b) under the condition: σ_{all} not in the creep range

$$T = 400 \text{ }^{\circ}\text{F} < \text{ }^{\circ}\text{F}$$

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)

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

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

UHX-12.5.1 Step 1

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

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

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

UHX-12.5.2 Step 2

$$M_{TS120} = \frac{D_0^2}{16} \cdot \left[((\rho_s - 1)(\rho_s^2 + 1) \cdot P_s) - (\rho_c - 1)(\rho_c^2 + 1) \cdot P_t \right] =$$

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

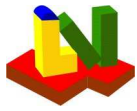
UHX-12.5.3 Step 3

$$\rho = \frac{l_{tx}}{h} = \frac{88.9 \text{ mm}}{88.9 \text{ mm}} = 1$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{25.4 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 23286 \text{ mm}^2}{\pi \cdot (666.8 \text{ mm})^2}}} = 26.29 \text{ mm}$$

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

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



ASME BPVC VIII-1 2021

Example E4.18.1 - E4.18.2 - E4.18.4 PTB-4-2021

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

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

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

$$F = \frac{(1 - \nu^*)}{E^*} \cdot (\lambda_S + \lambda_C + E^* \cdot \ln(K)) = \frac{(1 - 0.3179)}{84617 \text{ N/mm}^2} \cdot (0 \text{ N/mm}^2 + 52543 \text{ N/mm}^2 + 191733 \text{ N/mm}^2 \cdot \ln(1.419)) = 0.9645$$

UHX-12.5.6 Step 6

$$M^* = M_{TS} + \omega_C \cdot P_C - \omega_S \cdot P_S + M_{add} = 73250 \text{ N} + 4524 \text{ mm}^2 \cdot 0 \text{ N/mm}^2 - 0 \text{ mm}^2 \cdot 4.482 \text{ N/mm}^2 + 46442 \text{ N} = 119692 \text{ N}$$

$$M_{add} = (C - G_S) \cdot W_m / (2 \cdot \pi \cdot D_0) = 10441 \text{ lbf}$$

UHX-12.5.6 acc. UHX-12.6

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

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

σ	or	$\sigma \text{ acc. UHX12.6}$	$< 2 \cdot \sigma_B$
$\sigma = 38175 \text{ psi}$	or	45447 psi	$< 2 \cdot 20000 \text{ psi}$

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

τ	or	$\tau \text{ acc. UHX12.6}$	$\leq \text{MIN}[0.8 \sigma_B ; 0.533 S_y]$
$\tau = 4875 \text{ psi}$	or	4875 psi	$\leq 16000 \text{ psi}$

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	$< 1.5 \cdot \sigma_{all}$	or	$S_{PS}^*)$
$\sigma_S = \sigma_{Sm} + \sigma_{Sb} = 0 + 0 = 0 < 1.5 \cdot 0 \text{ or } 0$					
$\sigma_C = \sigma_{Cm} + \sigma_{Cb} = 0 + -392.7 = 392.7 < 1.5 \cdot 137.9 \text{ or } 413.7$					

*) 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:

Modulus of elasticity	elastic	N	(Y=Yes, N=No)
Shell	psi	Option 3	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:

$\sigma_S = 0 \text{ psi}$	$\leq 0 \text{ psi}$	$= S_{PSs}$
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with the allowable primary+secondary stress S_{PSs} , if the allowable stress σ_{allS} is outside of the creep range!

Analogously for the channel:

$\sigma_C = 56954 \text{ psi}$	$\leq 60000 \text{ psi}$	$= S_{PSc}$
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