



ASME BPVC VIII-1 2021

Example E4.18.5 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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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 4.18.5 - Fixed Tubesheet Exchanger , Configuration b, Tubesheet Integral with Shell, Extended as a Flange and Gasketed on the Channel Side

Step 1

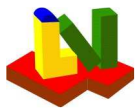
		LV Soft				ASME		Diff [%]
Eff. tube hole diameter	d^*	22,7	mm	0,9	in	0,9	in	0,25%
Effective pitch	p^*	31,8	mm	1,3	in	1,3	in	0,00%
Eff. ligament efficiency	μ^*			0,3		0,3		0,62%
Parameter	x_s			0,4		0,4		0,08%
Parameter	x_t			0,6		0,6		0,03%

Step 2

		LV Soft				ASME		Diff [%]
Coefficients for shell	δ_s	0,2	mm ³ /N	0,0	in ³ /lb f	0,0	in ³ /lb f	0,61%
	β_s	0,0	1/mm	0,7	1/in	0,7	1/in	0,00%
	k_s	97148,5	N	21840,0	lbf	21866,0	lbf	0,12%
	λ_s	6058,4	Mpa	878697,5 3238228,	psi	879437,0 3241928,	psi	0,08%
Shell axial rigidity	K_s	567115,4	N/mm	9	lbf/in	0	lbf/in	0,11%
Tube axial rigidity	K_t	6588,2	N/mm	37618,6	lbf/in	37666,0	lbf/in	0,13%
Stiffness ratio	K_{st}			0,1		0,1		0,01%
Stiffness ratio	J			0,0		0,0		0,13%

Step 3

		LV Soft				ASME		Diff [%]
Ratio of elasticity	E^*/E			0,3		0,3		0,88%
Eff. Poisson's ratio	ν^*			0,4		0,4		0,38%
Parameter: table 13.2	X_a			4,0		4,0		0,21%
	Z_d			0,0		0,0		0,66%
	Z_v			0,1		0,1		0,47%
	Z_m			0,4		0,4		0,29%



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Z_a	6,6	6,5	1,08%
Z_w	0,1	0,1	0,47%

Step 4

		LV Soft	ASME	Diff [%]
Diameter ratio	K	1,2	1,2	0,03%
Corfficient	F	0,5	0,5	0,52%
Parameter	Φ	0,7	0,7	0,58%
	Q_1	0,0	0,0	0,69%
	Q_{z1}	2,9	2,9	0,14%
	Q_{z2}	6,9	6,9	0,25%
	U	13,8	13,8	0,25%

Step 5

		LV Soft	ASME	Diff [%]
	$\gamma(^{\circ})$			
	ω_s	1732,0 mm ² 2,7 in ²	2,7 in ²	0,01%
	ω_s^*	-1712,1 mm ² -2,7 in ²	-2,7 in ²	0,01%
	ω_c	0,0 mm ² 0,0 in ²	0,0 in ²	0,00%
	ω_c^*	6218,5 mm ² 9,6 in ²	9,7 in ²	0,44%
	γ_b	-0,1	-0,1	0,38%

Summary table for Step 5 -Design Condition

Loading Case								
1	P_s	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_t	2,8	Mpa	400,0	psi	400,0	psi	0,00%
	γ	0,0	mm	0,0	in	0,0	in	0,00%
	W	2278818,0	N	512298,8	lbf	512473,0	lbf	0,03%
2	P_s	1,0	Mpa	150,0	psi	150,0	psi	0,00%
	P_t	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	γ	0,0	mm	0,0	in	0,0	in	0,00%
	W	0,0	N	0,0	lbf	0,0	lbf	0,00%
3	P_s	1,0	Mpa	150,0	psi	150,0	psi	0,00%
	P_t	2,8	Mpa	400,0	psi	400,0	psi	0,00%
	γ	0,0	mm	0,0	in	0,0	in	0,00%
	W	2278818,0	N	512298,8	lbf	512473,0	lbf	0,03%



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Summary table for Step 5 -Operation Condition

Loading Case								
1	P_s	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_t	2,8	Mpa	400,0	psi	400,0	psi	0,00%
	γ	-1,2	mm	0,0	in	0,0	in	0,59%
	W	2278818,0	N	512298,8	lbf	512937,0	lbf	0,12%
2	P_s	1,0	Mpa	150,0	psi	150,0	psi	0,00%
	P_t	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	γ	-1,2	mm	0,0	in	0,0	in	0,59%
	W	1630898,0	N	366640,5	lbf	512937,0	lbf	28,52%
3	P_s	1,0	Mpa	150,0	psi	150,0	psi	0,00%
	P_t	2,8	Mpa	400,0	psi	400,0	psi	0,00%
	γ	-1,2	mm	0,0	in	0,0	in	0,59%
	W	2280923,0	N	512772,0	lbf	512937,0	lbf	0,03%
4	P_s	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_t	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	γ	-1,2	mm	0,0	in	0,0	in	0,59%
	W		N		lbf		lbf	

Summary table for Step 6 -Design Condition

Loading Case								
			LV Soft			ASME		Diff [%]
1	P_s'	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_t'	5935,7	Mpa	860906,2	psi	862002,0	psi	0,13%
	P_y		Mpa	0,0	psi	0,0	psi	0,00%
	P_w		Mpa	0,0	psi	0,0	psi	0,00%
	P_w	1,6	Mpa	232,2	psi	230,7	psi	0,64%
	P_{rim}	1,3	Mpa	181,5	psi	181,9	psi	0,24%
	P_e	-2,8	Mpa	-399,4	psi	-399,4	psi	0,00%
2	P_s'	-318,3	Mpa	-46159,2	psi	-46387,0	psi	0,49%
	P_t'	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_y	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_w	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_w	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_{rim}	0,1	Mpa	18,7	psi	18,7	psi	0,18%
	P_e	-0,1	Mpa	-21,4	psi	-21,5	psi	0,38%

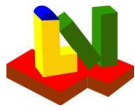


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3	P_s'	-318,3	Mpa	-46159,2	psi	-46387,0	psi	0,49%
	P_t'	5935,7	Mpa	860906,3	psi	862002,0	psi	0,13%
	P_y	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_ω	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_W	1,6	Mpa	232,2	psi	230,7	psi	0,64%
	P_{rim}	1,4	Mpa	200,2	psi	200,6	psi	0,20%
	P_e	-2,9	Mpa	-420,8	psi	-420,9	psi	0,02%

Summary table for Step 6 -Operation Condition

			LV Soft				ASME		Diff [%]
Loading Case									
1	P _s '	0,0	Mpa	0,0	psi	0,0	psi	0,00%	
	P _t '	5935,7	Mpa	860906,3	psi	862002,0	psi	0,13%	
	P _y	-8,6	Mpa	-1252,1	psi	-1254,0	psi	0,16%	
	P _ω	0,0	Mpa	0,0	psi	0,0	psi	0,00%	
	P _W	1,6	Mpa	235,6	psi	230,9	psi	2,04%	
	P _{rim}	1,3	Mpa	184,3	psi	181,9	psi	1,33%	
	P _e	-2,8	Mpa	-400,0	psi	-400,0	psi	0,00%	
2	P _s '	-318,3	Mpa	-46159,2	psi	-46387,0	psi	0,49%	
	P _t '	0,0	Mpa	0,0	psi	0,0	psi	0,00%	
	P _y	-8,6	Mpa	-1252,1	psi	-1254,0	psi	0,16%	
	P _ω	0,0	Mpa	0,0	psi	0,0	psi	0,00%	
	P _W	1,1	Mpa	166,0	psi	230,9	psi	28,10%	
	P _{rim}	0,1	Mpa	18,7	psi	18,7	psi	0,18%	
	P _e	-0,2	Mpa	-21,9	psi	-22,0	psi	0,36%	
3	P _s '	-318,3	Mpa	-46159,2	psi	-46387,0	psi	0,49%	
	P _t '	5935,7	Mpa	860906,3	psi	862002,0	psi	0,13%	
	P _y	-8,6	Mpa	-1252,1	psi	-1254,0	psi	0,16%	
	P _ω	0,0	Mpa	0,0	psi	0,0	psi	0,00%	
	P _W	1,6	Mpa	235,6	psi	230,9	psi	2,04%	
	P _{rim}	1,4	Mpa	203,3	psi	200,6	psi	1,37%	
	P _e	-2,9	Mpa	-421,4	psi	-421,5	psi	0,02%	
4	P _s '	0,0	Mpa	0,0	psi	0,0	psi	0,00%	
	P _t '	0,0	Mpa	0,0	psi	0,0	psi	0,00%	
	P _y	-8,6	Mpa	-1252,1	psi	-1254,0	psi	0,16%	
	P _ω	0,0	Mpa	0,0	psi	0,0	psi	0,00%	
	P _W		Mpa	0,0	psi		psi		

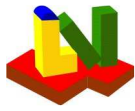


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	P_{rim}	0,0	Mpa	0,0	psi	0,0	psi	0,00%
	P_e	0,0	Mpa	-0,5	psi	-0,5	psi	0,60%

Summary table for Step 7 -Design Condition									
			LV Soft				ASME		Diff [%]
Loading Case									
1	Q ₂		-31313,6	N	-7039,6	lbf	-7040,7	psi	0,02%
	Q ₃				0,1		0,1	psi	0,27%
	F _m				0,1		0,1	psi	0,19%
	hg'		0,0	mm	0,0	in	0,0	psi	0,00%
	h		77,8	mm					
	h-hg'		77,8	mm	3,1	in	3,1	psi	0,02%
	σ _{elastic}		177,0	Mpa	25672,0	psi	25540,0	psi	0,52%
	1,5S		123,8	Mpa	26928,8	psi	27150,0	psi	0,81%
2	Q ₂		-1418,3	N	-318,8	lbf	-319,0	psi	0,05%
	Q ₃				0,1		0,1	psi	0,56%
	F _m				0,1		0,1	psi	0,04%
	hg'		0,0	mm	0,0	in	0,0	psi	0,00%
	h		77,8	mm					
	h-hg'		77,8	mm	3,1	in	3,1	psi	0,02%
	σ _{elastic}		8,8	Mpa	1270,4	psi	1269,0	psi	0,11%
	1,5S		123,8	Mpa	26928,8	psi	27150,0	psi	0,81%
3	Q ₂		-32731,9	N	-7358,4	lbf	-7359,7	psi	0,02%
	Q ₃				0,1		0,1	psi	0,73%
	F _m				0,1		0,1	psi	0,19%
	hg'		0,0	mm	0,0	in	0,0	psi	0,00%
	h		77,8	mm					
	h-hg'		77,8	mm	3,1	in	3,1	psi	0,02%
	σ _{elastic}		185,8	Mpa	26943,3	psi	26809,0	psi	0,50%
	1,5S		123,8	Mpa	26928,8	psi	27150,0	psi	0,81%

Summary table for Step 7 -Operation Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	Q ₂	-31096,5	N	-6990,8	lbf	-7044,2	psi	0,76%
	Q ₃			0,1		0,1		1,90%
	F _m			0,1		0,1		1,51%

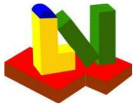


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		hg'	0,0	mm	0,0	in	0,0	in	0,00%
		h	77,8	mm					
		h-hg'	77,8	mm	3,1	in	3,1	in	0,02%
		$\sigma_{elastic}$	181,9	Mpa	26388,5	psi	25569,0	psi	3,21%
		S_{ps}	375,9	Mpa	54515,0	psi	54400,0	psi	0,21%
2		Q₂	-13986,0	N	-3144,2	lbf	-4259,3	psi	26,18%
		Q₃			1,0		1,3		26,50%
		F_m			0,5		0,7		25,41%
		hg'	0,0	mm	0,0	in	0,0	in	0,00%
		h	77,8	mm					
		h-hg'	77,8	mm	3,1	in	3,1	in	0,02%
		$\sigma_{elastic}$	49,9	Mpa	7240,3	psi	9658,0	psi	25,03%
		S_{ps}	375,9	Mpa	54515,0	psi	54400,0	psi	0,21%
3		Q₂	-32505,7	N	-7307,6	lbf	-7363,3	psi	0,76%
		Q₃			0,1		0,1		0,20%
		F_m			0,1		0,1		1,50%
		hg'	0,0	mm	0,0	in	0,0	in	0,00%
		h	77,8	mm					
		h-hg'	77,8	mm	3,1	in	3,1	in	0,02%
		$\sigma_{elastic}$	190,9	Mpa	27694,6	psi	26839,0	psi	3,19%
		S_{ps}	375,9	Mpa	54515,0	psi	54400,0	psi	0,21%

Summary table for Step 8 -Design Condition									
			LV Soft			ASME		Diff [%]	
Loading Case									
1	0,8S		99,0	Mpa	14362,0	psi	14480,0	psi	0,82%
2	0,8S		99,0	Mpa	14362,0	psi	14480,0	psi	0,82%
3	0,8S		99,0	Mpa	14362,0	psi	psi 14480,0	psi	0,82%

Summary table for Step 8 -Operation Condition									
		LV Soft				ASME		Diff [%]	
Loading Case									
1	0,8S		99,0 Mpa 14362,0 psi				14480,0 psi		0,82%
2									

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	0,8S	99,0 Mpa	14362,0 psi	14480,0 psi	0,82%
3	0,8S	99,0 Mpa	14362,0 psi	14480,0 psi	0,82%
4	0,8S	99,0 Mpa	14362,0 psi	14480,0 psi	0,82%

Summary table for Step 9 -Design Condition									
			LV Soft				ASME		Diff [%]
Loading Case									
1	F _{t,min}		-1,1				-1,1		0,01%
	σ _{t,1}		-27,8	Mpa	-4026,9	psi	-4024,0	psi	0,07%
	F _{t,max}		3,8				3,8		0,16%
	σ _{t,2}		52,3	Mpa	7590,0	psi	7570,0	psi	0,26%
2	F _{t,min}		-1,0				-1,0		0,11%
	σ _{t,1}		1,9	Mpa	269,6	psi	269,0	psi	0,23%
	F _{t,max}		3,7				3,7		0,24%
	σ _{t,2}		6,0	Mpa	864,9	psi	865,0	psi	0,01%
3	F _{t,min}		-1,1				-1,1		0,03%
	σ _{t,1}		-25,9	Mpa	-3757,3	psi	-3755,0	psi	0,06%
	F _{t,max}		3,8				3,8		0,17%
	σ _{t,2}		58,3	Mpa	8454,8	psi	8435,0	psi	0,24%

Summary table for Step 9 -Operation Condition									
			LV Soft				ASME		Diff [%]
Loading Case									
1	F _{t,min}		-1,1				-1,1		0,66%
	σ _{t,1}		-27,7	Mpa	-4014,0	psi	-4028,8	psi	0,37%
	F _{t,max}		3,9				3,8		1,17%
	σ _{t,2}		53,0	Mpa	7689,3	psi	7580,9	psi	1,43%
2	F _{t,min}		-4,2				-5,5		23,19%
	σ _{t,1}		-1,1	Mpa	-153,7	psi	-322,2	psi	52,29%
	F _{t,max}		10,6				13,3		20,23%
	σ _{t,2}		12,3	Mpa	1783,5	psi	2137,0	psi	16,54%
3	F _{t,min}		-1,1				-1,1		0,70%
	σ _{t,1}		-25,8	Mpa	-3743,8	psi	-3760,0	psi	0,43%
	F _{t,max}		3,8				3,8		1,15%
	σ _{t,2}		59,0	Mpa	8558,7	psi	8445,5	psi	1,34%



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Summary table for Step 9 -Design Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	$\sigma_{t,max}$	52,3	Mpa	7590,0	psi	7570,0	psi	0,26%
	$ \sigma_{t,min} $	27,8	Mpa	4026,9	psi	4024,0	psi	0,07%
	Fs			1,3		1,3		0,30%
	S _{tb}	39,3	Mpa	5701,1	psi	5693,9	psi	0,13%
2	$\sigma_{t,max}$	6,0	Mpa	864,9	psi	865,0	psi	0,01%
	$ \sigma_{t,min} $		Mpa		psi		psi	
	Fs							
	S _{tb}		Mpa		psi		psi	
3	$\sigma_{t,max}$	58,3	Mpa	8454,8	psi	8435,0	psi	0,24%
	$ \sigma_{t,min} $	25,9	Mpa	3757,3	psi	3755,0	psi	0,06%
	Fs			1,4		1,3		0,07%
	S _{tb}	39,2	Mpa	5685,0	psi	5677,0	psi	0,14%

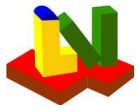
Summary table for Step 9 -Operation Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	$\sigma_{t,max}$	53,0	Mpa	7689,3	psi	7570,0	psi	1,58%
	$ \sigma_{t,min} $	27,7	Mpa	4014,0	psi	4028,8	psi	0,37%
	Fs			1,3		1,3		1,63%
	S _{tb}	39,8	Mpa	5779,2	psi	5690,9	psi	1,55%
2	$\sigma_{t,max}$	12,3	Mpa	1783,5	psi	2137,0	psi	16,54%
	$ \sigma_{t,min} $	1,1	Mpa	153,7	psi	322,2	psi	52,29%
	Fs			1,3		1,3		0,00%
	S _{tb}	42,2	Mpa	6122,6	psi	6129,4	psi	0,11%
3	$\sigma_{t,max}$	59,0	Mpa	8558,7	psi	8445,5	psi	1,34%
	$ \sigma_{t,min} $	25,8	Mpa	3743,8	psi	3760,0	psi	0,43%
	Fs			1,3		1,4		1,63%
	S _{tb}	39,7	Mpa	5762,8	psi	5674,9	psi	1,55%



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Summary table for Step 10 und 11 -Design Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	$\sigma_{s,m}$	0,2	Mpa	26,2	psi	26,1	psi	0,28%
	$\sigma_{s,b}$	-293,7	Mpa	-42603,9	psi	-42440,0	psi	0,39%
	σ_s	293,9	Mpa	42630,0	psi	42466,0	psi	0,39%
	1.5S_s	185,7	Mpa	26928,7	psi	27150,0	psi	0,82%
2	$\sigma_{s,m}$	-5,3	Mpa	-763,7	psi	-760,0	psi	0,49%
	$\sigma_{s,b}$	132,5	Mpa	19213,8	psi	19214,0	psi	0,00%
	σ_s	137,7	Mpa	19977,5	psi	19978,0	psi	0,00%
	1.5S_s	185,7	Mpa	26928,7	psi	27150,0	psi	0,82%
3	$\sigma_{s,m}$	-5,1	Mpa	-737,5	psi	-738,7	psi	0,16%
	$\sigma_{s,b}$	-161,3	Mpa	-23389,6	psi	-23227,0	psi	0,70%
	σ_s	166,4	Mpa	24127,1	psi	23966,0	psi	0,67%
	1.5S_s	185,7	Mpa	26928,7	psi	27150,0	psi	0,82%

Summary table for Step 10 und 11 -Operation Condition									
			LV Soft				ASME		Diff [%]
Loading Case									
1	$\sigma_{s,m}$		0,0	Mpa	0,1	psi	0,1	psi	0,81%
	$\sigma_{s,b}$		-292,6	Mpa	-42439,5	psi	-42484,0	psi	0,10%
	σ_s		292,6	Mpa	42439,4	psi	42484,0	psi	0,10%
	$S_{pS,s}$		375,9	Mpa	54515,0	psi	54400,0	psi	0,21%
2	$\sigma_{s,m}$		-5,4	Mpa	-786,3	psi	-786,1	psi	0,02%
	$\sigma_{s,b}$		80,2	Mpa	11628,6	psi	8633,0	psi	34,70%
	σ_s		85,6	Mpa	12414,9	psi	9419,0	psi	31,81%
	$S_{pS,s}$		375,9	Mpa	54515,0	psi	54400,0	psi	0,21%
3	$\sigma_{s,m}$		-5,3	Mpa	-763,6	psi	-764,8	psi	0,15%
	$\sigma_{s,b}$		-161,3	Mpa	-23389,6	psi	-23271,0	psi	0,51%
	σ_s		166,4	Mpa	24127,1	psi	24035,0	psi	0,38%
	$S_{pS,s}$		375,9	Mpa	54515,0	psi	54400,0	psi	0,21%



ASME BPVC VIII-1 2021
Example E4.18.5 PTB-4-2021



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Fixed Tubesheets - ASME BPVC VIII-1, UHX-13: 2021

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	b
Tubesheet integral with shell, gasketed with channel, flange extension		
Channel type (1=Cylinder, 2=Hemispherical)		1
Internal operating pressure shell side	P_s	150 psi
Internal operating pressure tube side	P_t	400 psi
Internal test pressure shell side	P_{sp}	psi
Internal test pressure tube side	P_{tp}	psi
Load case (1=operation, 2+3=test at 20°C, 4=other)		1

load case: operation

Calculation case per UHX-13.4(a):	(1-D1), (2-D2), (3-D3), (4-O4), (5-O1), (6-O2), (7-O3)	1
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Tube side pressure only ($P_s=0$) without differential thermal expansion

Tubesheet material	K02700-SA-516-70-Class:-Size:
Tube material	K01807-SA-214--Class:-Size:
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:

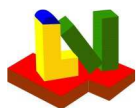
Operation	Tubesheet	Tubes	Shell
Temperature	700 °F	700 °F	700 °F
Thickness	3.062 in	0.083 in	0.1875 in
Outside diameter	40.5 in	1 in	35.13 in
Poisson's ratio	-	0.3	0.3
Allowance c_1	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in

Properties for the selected load case temperature

Strength operat.	17952 psi	10430 psi	17952 psi
Safety operation	1	1	1
Modulus of elasticity	2.547e+7 psi	2.547e+7 psi	2.547e+7 psi
Thermal expansion	7.586 1E-6/°F	7.586 1E-6/°F	7.586 1E-6/°F
Yield strength	27257 psi	18655 psi	27257 psi
Limit temperature	1000 °F	1000 °F	1000 °F
Allow. stress	17952 psi	10430 psi	17952 psi
Prim.+sec. str.	54515 psi		54515 psi

Properties for testing at 20°C

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



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1
Tube pattern	(1=Triangle, 2=Square)		1
Number of tubes		N_t	649
Expanded length of tube in tubesheet		$l_{t,x}$	2.909 in
Expanded length ratio $l_{t,x}/h$		ρ	0.95
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63 in
Perimeter of the outermost tubes	UHX-12.2	C_p	in
Total area enclosed by C_p	UHX-12.2	A_p	in ²
Tube pitch (center distance)		p	1.25 in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0 in ²
Depth of tube side pass partition groove		h_g	0 in
Tube length between inner tubesheet faces		L	161.9 in
Unsupported tube span for buckling		l	59 in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	1
Equivalent free buckling length $k \cdot l$		l_t	59 in
Bellows inside diameter at its convolution height		D_j	38.5 in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	11388 lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	1
Mean temperature along the shell length		T_{sm}	550 °F
Mean temperature along the tube length		T_{tm}	510 °F
Mean coefficient of thermal expansion of shell at T_{sm}		α_{sm}	7.3 1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}		α_{tm}	7.3 1E-6/°F

Material properties for mean operating temperature

UHX-13.8: Specification of values only for radial differential thermal expansion (type abc)

(Thermal expansion = 0 for ambient temperature=20°C=68°F)

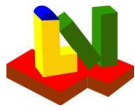
Tubesheet metal temperature at the rim	T'_r	68 °F
Channel metal temperature at the tubesheet	T'_c	68 °F
Shell metal temperature at the tubesheet	T'_s	68 °F
Mean coefficient of thermal expansion of		
Tubesheet at T'_r	α'_r	6.389 1E-6/°F
Channel at T'_c	α'_c	1E-6/°F
Shell unreinforced (for $l+l'=0$) at T'_s	α'_s	6.389 1E-6/°F
Shell reinforced acc. UHX-13.6 at T'_s	α'_s	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1	in
Bolt circle diameter	C	38.88 in
Number of bolts	n	68
Bolt root diameter	d_B	0.62 in
Total bolt area	A_b	20.53 in ²
Bolt material	G41400-SA-193-B7-Class:-Size:<=64	
Strength for operation	K_s	25000 psi
Strength for test	K_{sp}	25000 psi
Safety for operation	S_s	1
Safety for test	S_{sp}	1
Stress intensification factor for testing	F_s	1

Gasket

	Shell Type d		Channel Type b,c,d
Contact outside diameter	G_a	in	37.31 in
Contact inside diameter	G_i	in	36.31 in
Basic seating width	b_0	in	0.255 in
Gasket factor (Table 2-5.1)	m		3.75
Gasket seating pressure	Y	psi	7600 psi
Diameter of gasket force	G	in	36.81 in
Poisson's ratio	ν	0.3	0.3



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Results acc. UHX-9

	Shell	Channel
Effective seating width	b in	0.2505 in
Gasket operating force	W lbf	512301 lbf
Total req. bolt root area	A_m in ²	20.49 in ²
$A_m < \text{actual bolt area} = 13245 \text{ mm}^2$		
Tubesheet flange thickness	h_r in	1.235 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(A_m+A_b)· K_{sp}/S_{sp} , App.2-5	W 512774 lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J 0.003504
Channel shell thickness without allowances	t_c in
Shell thickness without allowances	t_s 0.1875 in
Shell inside diameter corroded (type abc)	D_s 34.76 in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{IT} 2.547e+7 psi
Tube material allowable stress basis at T	K_{IT} 12353 psi
Tube material allowable stress safety at T	S_{IT} 1
Basic ligament efficiency for shear	μ 0.2
Effective tube hole diameter	d^* 0.8915 in
Effective pitch	p^* 1.25 in
Effective ligament efficiency for shear	μ^* 0.2868
Effective depth of pass partition groove	h_g' 0 in
Equivalent radius of outer tube limit circle	a_0 17.13 in
Radial channel dimension (type a: $D_c/2$, else: $G_c/2$)	a_c 18.4 in
Radial shell dimension (type d: $G_s/2$, else: $D_s/2$)	a_s 17.38 in
Ratio = a_c/a_0	ρ_C 1.074
Ratio = a_s/a_0	ρ_S 1.014
Parameter = $1-N_t \cdot (0.5 \cdot d_a \text{ TUBE}/a_0)^2$	x_s 0.4471
Parameter = $1-N_t \cdot (0.5 \cdot d_i \text{ TUBE}/a_0)^2$	x_t 0.6154
Type abc: Coefficients for shell pressure	δ_S 0.198 mm ³ /N
β_S 8.522 1/ft	k_S 21840 lbf
	λ_S 878699 psi

Step 2

Shell axial rigidity K_s or K_s^*	K_s 3238229 lbf/in
Tube axial rigidity	K_t 37618 lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st} 0.1326
Stiffness ratio $K_j/(K_s+K_j)$	J 0.003504

Step 3

Effective modulus of el. tubesheet	UHX-11.3	E^* 6722361 psi
Ratio of elasticity tubesheet		E^*/E 0.2639
effective Poisson's ratio tubesheet		ν^* 0.3634
Parameter for table UHX-13.1		X_a 3.961
Z_d 0.02465 Z_v 0.06434 Z_m 0.3718 Z_a 6.53 Z_w 0.06434		

Step 4

Diameter ratio = A/D_0		K 1.182
F 0.4868	Φ 0.6637	Q_1 -0.02266
Q_{z1} 2.854	Q_{z2} 6.881	U 13.76

UHX-13.5.5 Step 5, coefficients

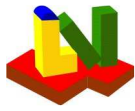
$\gamma(^{\circ})$ 0 in	ω_S 2.685 in ²	ω_S^* -2.654 in ²
ω_C 0 in ²	ω_C^* 9.639 in ²	γ_b -0.06045

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_w 0 psi

Step 6

P_s' 0 psi	P_t' 860900 psi	P_y 0 psi
P_w 231.4 psi	P_{rim} 180.8 psi	P_e -399.4 psi



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

UHX-13.5.7 Step 7

$$Q_2 = -7049 \text{ lbf} \quad Q_3 = 0.09763 \quad F_m = 0.09758$$

Strength condition for the tubesheet bending stress, case 1

$$\sigma = 25520 \text{ psi} < 1.5 \cdot \sigma_B = 1.5 \cdot 17952 \text{ psi} \quad \text{case 1-3}$$

$$< S_{PS} = 54515 \text{ psi} \quad \text{case 4-7}$$

Step 8

Strength condition for the tubesheet shear stress:

$$\tau = \text{psi} \leq \text{MIN}[0.8\sigma_B; 0.533 S_y] = 14362 \text{ psi}$$

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

$$F_{tmin} = -1.082 \quad F_{tmax} = 3.807$$

$$x_{min} = 0 \quad x_{max} = 3.971$$

$$\sigma_{T,1} = -4030 \text{ psi} \quad \sigma_{T,2} = 7570 \text{ psi}$$

$$\sigma_{tmax} = 7570 \text{ psi} \leq \sigma_T = 10430 \text{ psi} \quad \text{for calculation case 1-3}$$

$$\leq 2 \cdot \sigma_T = 20860 \text{ psi} \quad \text{for calculation case 4-7}$$

Tube weld force $W_t = 1810 \text{ lbf} \leq W_{t,all} = 0 \text{ lbf}$
(only if weld thickness < tube thickness: enter $W_t, all > 0$ acc. UW-20)

$$r_t = 0.3255 \text{ in} \quad F_t = 181.2 \quad C_t = 1.347 \quad F_s = 164.2$$

$$|\sigma_{tmin}| = -4030 \text{ psi} \leq S_{tb} = 5683 \text{ psi} \quad (\text{only } \sigma_{tmin} < 0 \text{ buckl.})$$

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σ_{Sm} in the shell

Region of smaller wall thickness $t_s = 0.1875 \text{ in}$: (calculation case)

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

$$\sigma_{Sm} = 26.09 \text{ psi} \leq 2 \cdot 17952 \text{ psi} = 2 \cdot \sigma_{allS} \quad (4-7)$$

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

$$26.09 \text{ psi} < \text{Min}(8493 \text{ psi}, 16994 \text{ psi})$$

ASME external pressure chart CS-2 $A = 0.001334$

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

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

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

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

ASME external pressure chart $A = \text{psi}$

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_s in the shell and σ_c in the channel

$$\sigma_s = |\sigma_{Sm}| + |\sigma_{Sb}| = 42441 \text{ psi} \leq 1.5 \cdot \sigma_{allS}, S_{PSs} \text{ or } S_{PSs1}$$

$$\sigma_s = 26.09 \text{ psi} + -42415 \text{ psi} \leq 26929 \text{ psi}$$

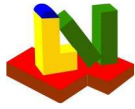
$$\sigma_c = |\sigma_{Cm}| + |\sigma_{Cb}| = 0 \text{ psi} \leq 1.5 \cdot \sigma_{allC} \text{ or } S_{PSc}$$

$$\sigma_c = 0 \text{ psi} + 0 \text{ psi} \leq 0 \text{ psi}$$

Minimum shell length with uniform thickness $l_{Sm} = 4.595 \text{ in}$

Minimum channel thickness with uniform thickness $l_{Cm} = \text{in}$

Strength condition UHX-13.5.11 is violated!



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

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

Modulus of elasticity	elastic	Option 3
Shell	2.547e+7 psi	2.547e+7 psi
Channel	psi	psi

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

$$\sigma_S = \mathbf{42441} \text{ psi} \leq \mathbf{54515} \text{ psi} = S_{PSS}$$

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

$$\sigma_C = \mathbf{0} \text{ psi} \leq \mathbf{0} \text{ psi} = S_{PSC}$$

Geometric conditions:
valid

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

13.4(d) If: Tube sheet thickness= 3.062 in < 1 in
= Tube outside diameter, the tubesheet deformation must be considered.

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance $c_2 > 0$) and without corrosion ($c_2 = 0$). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Equations

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

Allowable primary + secondary shell stress acc. UG-23(e):

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

$$54515 \text{ psi} = 3 \cdot 17952 \text{ psi} \quad \text{or } 2 \cdot 27257 \text{ psi}$$

(b) under the condition: SigZul not in the creep range:

$$T = 700 \text{ }^{\circ}\text{F} < 1000 \text{ }^{\circ}\text{F}$$

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

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.77 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 77.77 \text{ mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.4 \text{ mm} + 25.4 \text{ mm}) = 870.2 \text{ mm}$$

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

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

UHX-13.5.2 Step 2

$$K_s = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567115 \text{ N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6588 \text{ N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.89 \text{ mm}}{77.77 \text{ mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{31.75 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 0 \text{ mm}^2}{\pi \cdot (870.2 \text{ mm})^2}}} = 31.75 \text{ mm}$$

$$d^* = \text{Max} \left\{ \begin{matrix} d_1^* \\ d_2^* \end{matrix} \right\}$$

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho \right) \Leftrightarrow d_2^* = \left(25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm} \cdot \frac{175622 \text{ N/mm}^2}{175622 \text{ N/mm}^2} \cdot \frac{71.91 \text{ N/mm}^2}{123.8 \text{ N/mm}^2} \cdot 0.95 \right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75 \text{ mm} - 22.64 \text{ mm}}{31.75 \text{ mm}} = 0.2868$$



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Fixed Tubesheets - ASME BPVC VIII-1, UHX-13: 2021

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	b
Tubesheet integral with shell, gasketed with channel, flange extension		
Channel type (1=Cylinder, 2=Hemispherical)		1
Internal operating pressure shell side	P_s	150 psi
Internal operating pressure tube side	P_t	400 psi
Internal test pressure shell side	P_{sp}	psi
Internal test pressure tube side	P_{tp}	psi
Load case (1=operation, 2+3=test at 20°C, 4=other)		1

load case: operation

Calculation case per UHX-13.4(a):	(1-D1), (2-D2), (3-D3), (4-O4), (5-O1), (6-O2), (7-O3)	2
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Shell side pressure only ($P_t=0$) without differential thermal expansion

Tubesheet material	K02700-SA-516-70-Class:-Size:
Tube material	K01807-SA-214--Class:-Size:
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:

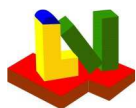
Operation	Tubesheet	Tubes	Shell
Temperature	700 °F	700 °F	700 °F
Thickness	3.062 in	0.083 in	0.1875 in
Outside diameter	40.5 in	1 in	35.13 in
Poisson's ratio	-	0.3	0.3
Allowance c_1	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in

Properties for the selected load case temperature

Strength operat.	17952 psi	10430 psi	17952 psi
Safety operation	1	1	1
Modulus of elasticity	2.547e+7 psi	2.547e+7 psi	2.547e+7 psi
Thermal expansion	7.586 1E-6/°F	7.586 1E-6/°F	7.586 1E-6/°F
Yield strength	27257 psi	18655 psi	27257 psi
Limit temperature	1000 °F	1000 °F	1000 °F
Allow. stress	17952 psi	10430 psi	17952 psi
Prim.+sec. str.	54515 psi		54515 psi

Properties for testing at 20°C

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



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1
Tube pattern	(1=Triangle, 2=Square)		1
Number of tubes		N_t	649
Expanded length of tube in tubesheet		$l_{t,x}$	2.909 in
Expanded length ratio $l_{t,x}/h$		ρ	0.95
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63 in
Perimeter of the outermost tubes	UHX-12.2	C_p	in
Total area enclosed by C_p	UHX-12.2	A_p	in ²
Tube pitch (center distance)		p	1.25 in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0 in ²
Depth of tube side pass partition groove		h_g	0 in
Tube length between inner tubesheet faces		L	161.9 in
Unsupported tube span for buckling		l	59 in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	1
Equivalent free buckling length $k \cdot l$		l_t	59 in
Bellows inside diameter at its convolution height		D_j	38.5 in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	11388 lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	1
Mean temperature along the shell length		T_{sm}	550 °F
Mean temperature along the tube length		T_{tm}	510 °F
Mean coefficient of thermal expansion of shell at T_{sm}		α_{sm}	7.3 1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}		α_{tm}	7.3 1E-6/°F

Material properties for mean operating temperature

UHX-13.8: Specification of values only for radial differential thermal expansion (type abc)

(Thermal expansion = 0 for ambient temperature=20°C=68°F)

Tubesheet metal temperature at the rim	T'_r	68 °F
Channel metal temperature at the tubesheet	T'_c	68 °F
Shell metal temperature at the tubesheet	T'_s	68 °F
Mean coefficient of thermal expansion of		
Tubesheet at T'_r	α'_r	6.389 1E-6/°F
Channel at T'_c	α'_c	1E-6/°F
Shell unreinforced (for $l+l'=0$) at T'_s	α'_s	6.389 1E-6/°F
Shell reinforced acc. UHX-13.6 at T'_s	α'_s	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1	in
Bolt circle diameter	C	38.88 in
Number of bolts	n	68
Bolt root diameter	d_B	0.62 in
Total bolt area	A_b	20.53 in ²
Bolt material	G41400-SA-193-B7-Class:-Size:<=64	
Strength for operation	K_s	25000 psi
Strength for test	K_{sp}	25000 psi
Safety for operation	S_s	1
Safety for test	S_{sp}	1
Stress intensification factor for testing	F_s	1

Gasket

	Shell Type d	Channel Type b,c,d
Contact outside diameter	G_a	37.31 in
Contact inside diameter	G_i	in
Basic seating width	b_0	0.255 in
Gasket factor (Table 2-5.1)	m	3.75
Gasket seating pressure	Y	7600 psi
Diameter of gasket force	G	36.81 in
Poisson's ratio	ν	0.3



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Results acc. UHX-9

Effective seating width
Gasket operating force
Total req. bolt root area
 $A_m < \text{actual bolt area} = 13245 \text{ mm}^2$
Tubesheet flange thickness

Shell
b in
W lbf
 A_m in²
 h_r in

Channel
0.2505 in
0 lbf
8.801 in²
0.9895 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)
Max. gasket seating force chan.=0.5(A_m+A_b)· K_{sp}/S_{sp} , App.2-5
Stiffness ratio Bellows/Shell (=1 without bellows)
Channel shell thickness without allowances
Shell thickness without allowances
Shell inside diameter corroded (type abc)

Y (Y,N)
W 0 lbf
J 0.003504
 t_c in
 t_s 0.1875 in
 D_s 34.76 in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T
Tube material allowable stress basis at T
Tube material allowable stress safety at T
Basic ligament efficiency for shear
Effective tube hole diameter
Effective pitch
Effective ligament efficiency for shear
Effective depth of pass partition groove
Equivalent radius of outer tube limit circle
Radial channel dimension (type a: $D_c/2$, else: $G_c/2$)
Radial shell dimension (type d: $G_s/2$, else: $D_s/2$)
Ratio = a_c/a_0
Ratio = a_s/a_0
Parameter = $1-N_t \cdot (0.5 \cdot d_a \text{TUBE}/a_0)^2$
Parameter = $1-N_t \cdot (0.5 \cdot d_i \text{TUBE}/a_0)^2$
Type abc: Coefficients for shell pressure
 β_s 8.522 1/ft
 k_s 21840 lbf

E_{IT} 2.547e+7 psi
 K_{IT} 12353 psi
 S_{IT} 1
 μ 0.2
 d^* 0.8915 in
 p^* 1.25 in
 μ^* 0.2868
 h_g' 0 in
 a_0 17.13 in
 a_c 18.4 in
 a_s 17.38 in
 ρ_C 1.074
 ρ_S 1.014
 x_s 0.4471
 x_t 0.6154
 δ_S 0.198 mm³/N
 λ_S 878699 psi

Step 2

Shell axial rigidity K_s or K_s^*
Tube axial rigidity
Stiffness ratio $K_s/(N_t \cdot K_t)$
Stiffness ratio $K_j/(K_s+K_j)$

K_s 3238229 lbf/in
 K_t 37618 lbf/in
 K_{st} 0.1326
J 0.003504

Step 3

Effective modulus of el. tubesheet UHX-11.3
Ratio of elasticity tubesheet
effective Poisson's ratio tubesheet
Parameter for table UHX-13.1
 Z_d 0.02465 Z_v 0.06434 Z_m 0.3718 Z_a 6.529 Z_w 0.06434

E^* 6722551 psi
 E^*/E 0.2639
 v^* 0.3634
 X_a 3.961
 Z_w 0.06434

Step 4

Diameter ratio = A/D_0
F 0.4868
 Q_{z1} 2.854

Φ 0.6637
 Q_{z2} 6.881

K 1.182
 Q_1 -0.02266
U 13.76

UHX-13.5.5 Step 5, coefficients

$\gamma(^*)$ 0 in
 ω_C 0 in²

ω_S 2.685 in²
 ω_C^* 9.639 in²

ω_S^* -2.654 in²
 γ_b -0.06045

Results acc. UHX-13.8 Radial differential thermal expansion

T_r 68 °F
 P_s^* 0 psi

T_s^* 68 °F
 P_c^* 0 psi

T_c^* 68 °F
 P_w 0 psi

Step 6

P_s' -46159 psi
 P_w 0 psi

P_t' 0 psi
 P_{rim} 18.67 psi

P_y 0 psi
 P_e -21.42 psi



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

UHX-13.5.7 Step 7

$$Q_2 = -319.3 \text{ lbf} \quad Q_3 = 0.07895 \quad F_m = 0.09025$$

Strength condition for the tubesheet bending stress, case 1-3

$$\sigma = 1266 \text{ psi} < 1.5 \cdot \sigma_B = 1.5 \cdot 17952 \text{ psi} \quad \text{case 1-3}$$

$$< S_{PS} = 54515 \text{ psi} \quad \text{case 4-7}$$

Step 8

Strength condition for the tubesheet shear stress:

$$\tau = \text{psi} \leq \text{MIN}[0.8\sigma_B; 0.533 S_y] = 14362 \text{ psi}$$

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

$$F_{tmin} = -1.013 \quad F_{tmax} = 3.659$$

$$x_{min} = 0 \quad x_{max} = 3.971$$

$$\sigma_{T,1} = 269.5 \text{ psi} \quad \sigma_{T,2} = 863.9 \text{ psi}$$

$$\sigma_{tmax} = 863.9 \text{ psi} \leq \sigma_T = 10430 \text{ psi} \quad \text{for calculation case 1-3}$$

$$\leq 2 \cdot \sigma_T = 20860 \text{ psi} \quad \text{for calculation case 4-7}$$

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

$$r_t = 0.3255 \text{ in} \quad F_t = 181.2 \quad C_t = 1.421 \quad F_s = 164.2$$

$$|\sigma_{tmin}| = 269.5 \text{ psi} \leq S_{tb} = 5387 \text{ psi} \quad (\text{only } \sigma_{tmin} < 0 \text{ buckl.})$$

Strength acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σ_{Sm} in the shell

Region of smaller wall thickness $t_s = 0.1875 \text{ in}$: (calculation case)

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

$$\sigma_{Sm} = -763.7 \text{ psi} \leq 2 \cdot 17952 \text{ psi} = 2 \cdot \sigma_{allS} \quad (4-7)$$

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

$$-763.7 \text{ psi} < \text{Min}(8493 \text{ psi}, 16994 \text{ psi})$$

ASME external pressure chart CS-2 $A = 0.001334$

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

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

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

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

ASME external pressure chart $A = \text{psi}$

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_s in the shell and σ_c in the channel

$$\sigma_s = |\sigma_{Sm}| + |\sigma_{Sb}| = 19987 \text{ psi} \leq 1.5 \cdot \sigma_{allS}, S_{PSs} \text{ or } S_{PSs1}$$

$$\sigma_s = -763.7 \text{ psi} + 19223 \text{ psi} \leq 26929 \text{ psi}$$

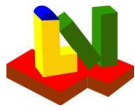
$$\sigma_c = |\sigma_{Cm}| + |\sigma_{Cb}| = 0 \text{ psi} \leq 1.5 \cdot \sigma_{allC} \text{ or } S_{PSc}$$

$$\sigma_c = 0 \text{ psi} + 0 \text{ psi} \leq 0 \text{ psi}$$

Minimum shell length with uniform thickness $l_{Sm} = 4.595 \text{ in}$

Minimum channel thickness with uniform thickness $l_{Cm} = \text{in}$

Strength condition UHX-13.5.11 is satisfied



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

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

Modulus of elasticity	elastic	Option 3
Shell	2.547e+7 psi	2.547e+7 psi
Channel	psi	psi

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

$\sigma_S =$ **19987** psi \leq 54515 psi $= S_{PSS}$

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

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

Geometric conditions:
valid

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

13.4(d) If: Tube sheet thickness= 3.062 in < 1 in

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

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance $c_2 > 0$) and without corrosion ($c_2 = 0$). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Equations

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

Allowable primary + secondary shell stress acc. UG-23(e):

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

$$54515 \text{ psi} = 3 \cdot 17952 \text{ psi} \quad \text{or } 2 \cdot 27257 \text{ psi}$$

(b) under the condition: SigZul not in the creep range:

$$T = 700 \text{ }^{\circ}\text{F} < 1000 \text{ }^{\circ}\text{F}$$

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

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.77 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 77.77 \text{ mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.4 \text{ mm} + 25.4 \text{ mm}) = 870.2 \text{ mm}$$

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

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

UHX-13.5.2 Step 2

$$K_s = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567115 \text{ N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6588 \text{ N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.89 \text{ mm}}{77.77 \text{ mm}} = 0.95$$

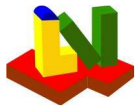
$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{31.75 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 0 \text{ mm}^2}{\pi \cdot (870.2 \text{ mm})^2}}} = 31.75 \text{ mm}$$

$$d^* = \text{Max} \left\{ \begin{matrix} d_1^* \\ d_2^* \end{matrix} \right\}$$

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho \right) \Leftrightarrow d_2^* = \left(25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm} \cdot \frac{175622 \text{ N/mm}^2}{175622 \text{ N/mm}^2} \cdot \frac{71.91 \text{ N/mm}^2}{123.8 \text{ N/mm}^2} \cdot 0.95 \right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75 \text{ mm} - 22.64 \text{ mm}}{31.75 \text{ mm}} = 0.2868$$



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Fixed Tubesheets - ASME BPVC VIII-1, UHX-13: 2021

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	b
Tubesheet integral with shell, gasketed with channel, flange extension		
Channel type (1=Cylinder, 2=Hemispherical)		1
Internal operating pressure shell side	P_s	150 psi
Internal operating pressure tube side	P_t	400 psi
Internal test pressure shell side	P_{sp}	psi
Internal test pressure tube side	P_{tp}	psi
Load case (1=operation, 2+3=test at 20°C, 4=other)		1
load case: operation		
Calculation case per UHX-13.4(a): (1-D1), (2-D2), (3-D3), (4-O4), (5-O1), (6-O2), (7-O3)		3

Tube and shell side pressure acting without differential thermal expansion

Tubesheet material	K02700-SA-516-70-Class:-Size:
Tube material	K01807-SA-214--Class:-Size:
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:

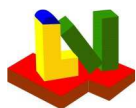
Operation	Tubesheet	Tubes	Shell
Temperature	700 °F	700 °F	700 °F
Thickness	3.062 in	0.083 in	0.1875 in
Outside diameter	40.5 in	1 in	35.13 in
Poisson's ratio	-	0.3	0.3
Allowance c_1	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in

Properties for the selected load case temperature

Strength operat.	17952 psi	10430 psi	17952 psi
Safety operation	1	1	1
Modulus of elasticity	2.547e+7 psi	2.547e+7 psi	2.547e+7 psi
Thermal expansion	7.586 1E-6/°F	7.586 1E-6/°F	7.586 1E-6/°F
Yield strength	27257 psi	18655 psi	27257 psi
Limit temperature	1000 °F	1000 °F	1000 °F
Allow. stress	17952 psi	10430 psi	17952 psi
Prim.+sec. str.	54515 psi		54515 psi

Properties for testing at 20°C

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



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1
Tube pattern	(1=Triangle, 2=Square)		1
Number of tubes		N_t	649
Expanded length of tube in tubesheet		$l_{t,x}$	2.909 in
Expanded length ratio $l_{t,x}/h$		ρ	0.95
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63 in
Perimeter of the outermost tubes	UHX-12.2	C_p	in
Total area enclosed by C_p	UHX-12.2	A_p	in ²
Tube pitch (center distance)		p	1.25 in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0 in ²
Depth of tube side pass partition groove		h_g	0 in
Tube length between inner tubesheet faces		L	161.9 in
Unsupported tube span for buckling		l	59 in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	1
Equivalent free buckling length $k \cdot l$		l_t	59 in
Bellows inside diameter at its convolution height		D_j	38.5 in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	11388 lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	1
Mean temperature along the shell length		T_{sm}	550 °F
Mean temperature along the tube length		T_{tm}	510 °F
Mean coefficient of thermal expansion of shell at T_{sm}		α_{sm}	7.3 1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}		α_{tm}	7.3 1E-6/°F

Material properties for mean operating temperature

UHX-13.8: Specification of values only for radial differential thermal expansion (type abc)

(Thermal expansion = 0 for ambient temperature=20°C=68°F)

Tubesheet metal temperature at the rim	T'	68 °F
Channel metal temperature at the tubesheet	T'_c	68 °F
Shell metal temperature at the tubesheet	T'_s	68 °F
Mean coefficient of thermal expansion of		
Tubesheet at T'	α'	6.389 1E-6/°F
Channel at T'_c	α'_c	1E-6/°F
Shell unreinforced (for $l+l'=0$) at T'_s	α'_s	6.389 1E-6/°F
Shell reinforced acc. UHX-13.6 at T'_s	α'_s	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1	in
Bolt circle diameter	C	38.88 in
Number of bolts	n	68
Bolt root diameter	d_B	0.62 in
Total bolt area	A_b	20.53 in ²
Bolt material	G41400-SA-193-B7-Class:-Size:<=64	
Strength for operation	K_s	25000 psi
Strength for test	K_{sp}	25000 psi
Safety for operation	S_s	1
Safety for test	S_{sp}	1
Stress intensification factor for testing	F_s	1

Gasket

	Shell Type d		Channel Type b,c,d
Contact outside diameter	G_a	in	37.31 in
Contact inside diameter	G_i	in	in
Basic seating width	b_0	in	0.255 in
Gasket factor (Table 2-5.1)	m		3.75
Gasket seating pressure	Y	psi	7600 psi
Diameter of gasket force	G	in	36.81 in
Poisson's ratio	ν	0.3	0.3



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Results acc. UHX-9

	Shell	Channel
Effective seating width	b in	0.2505 in
Gasket operating force	W lbf	512301 lbf
Total req. bolt root area	A _m in ²	20.49 in ²
A _m < actual bolt area = 13245 mm ²		
Tubesheet flange thickness	h _r in	1.235 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(A _m +A _b)·K _{sp} /S _{sp} , App.2-5	W 512774 lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J 0.003504
Channel shell thickness without allowances	t _c in
Shell thickness without allowances	t _s 0.1875 in
Shell inside diameter corroded (type abc)	D _s 34.76 in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E _{IT} 2.547e+7 psi
Tube material allowable stress basis at T	K _{IT} 12353 psi
Tube material allowable stress safety at T	S _{IT} 1
Basic ligament efficiency for shear	μ 0.2
Effective tube hole diameter	d* 0.8915 in
Effective pitch	p* 1.25 in
Effective ligament efficiency for shear	μ* 0.2868
Effective depth of pass partition groove	h _g ' 0 in
Equivalent radius of outer tube limit circle	a ₀ 17.13 in
Radial channel dimension (type a: D _c /2, else: G _c /2)	a _c 18.4 in
Radial shell dimension (type d: G _s /2, else: D _s /2)	a _s 17.38 in
Ratio = a _c /a ₀	ρ _C 1.074
Ratio = a _s /a ₀	ρ _S 1.014
Parameter = 1-N _t ·(0.5·d _a TUBE/a ₀) ²	x _s 0.4471
Parameter = 1-N _t ·(0.5·d _i TUBE/a ₀) ²	x _t 0.6154
Type abc: Coefficients for shell pressure	δ _S 0.198 mm ³ /N
β _S 8.522 1/ft	k _S 21840 lbf
	λ _S 878699 psi

Step 2

Shell axial rigidity K _s or K _s *	K _s 3238229 lbf/in
Tube axial rigidity	K _t 37618 lbf/in
Stiffness ratio K _s /(N _t ·K _t)	K _{st} 0.1326
Stiffness ratio K _j /(K _s +K _j)	J 0.003504

Step 3

Effective modulus of el. tubesheet	UHX-11.3				E*	6722551	psi
Ratio of elasticity tubesheet					E*/E	0.2639	
effective Poisson's ratio tubesheet					v*	0.3634	
Parameter for table UHX-13.1					X _a	3.961	
Z _d	0.02465	Z _v	0.06434	Z _m	0.3718	Z _a	6.529
						Z _w	0.06434

Step 4

Diameter ratio = A/D ₀		K	1.182
F 0.4868	Φ 0.6637	Q ₁	-0.02266
Q _{z1} 2.854	Q _{z2} 6.881	U	13.76

UHX-13.5.5 Step 5, coefficients

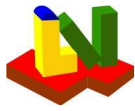
Y(*) 0 in	ω _S 2.685 in ²	ω _S *	-2.654 in ²
ω _C 0 in ²	ω _C *	9.639 in ²	γ _b -0.06045

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 _w 0 psi

Step 6

P _s ' -46159 psi	P _t ' 860900 psi	P _y	0 psi
P _w 231.4 psi	P _{rim} 199.5 psi	P _e	-420.8 psi



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

UHX-13.5.7 Step 7

$$Q_2 = -7369 \text{ lbf} \quad Q_3 = 0.09668 \quad F_m = 0.09721$$

Strength condition for the tubesheet bending stress, case 3

$$\sigma = 26783 \text{ psi} < 1.5 \cdot \sigma_B = 1.5 \cdot 17952 \text{ psi} \quad \text{case 1-3}$$

$$< S_{PS} = 54515 \text{ psi} \quad \text{case 4-7}$$

Step 8

Strength condition for the tubesheet shear stress:

$$\tau = \text{psi} \leq \text{MIN}[0.8\sigma_B; 0.533 S_y] = 14362 \text{ psi}$$

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

$$F_{tmin} = -1.078 \quad F_{tmax} = 3.799$$

$$x_{min} = 0 \quad x_{max} = 3.971$$

$$\sigma_{T,1} = -3760 \text{ psi} \quad \sigma_{T,2} = 8434 \text{ psi}$$

$$\sigma_{tmax} = 8434 \text{ psi} \leq \sigma_T = 10430 \text{ psi} \quad \text{for calculation case 1-3}$$

$$\leq 2 \cdot \sigma_T = 20860 \text{ psi} \quad \text{for calculation case 4-7}$$

Tube weld force $W_t = 2017 \text{ lbf} \leq W_{t,all} = 0 \text{ lbf}$
(only if weld thickness < tube thickness: enter $W_t, all > 0$ acc. UW-20)

$$r_t = 0.3255 \text{ in} \quad F_t = 181.2 \quad C_t = 1.35 \quad F_s = 164.2$$

$$|\sigma_{tmin}| = |-3760 \text{ psi}| \leq S_{tb} = 5667 \text{ psi} \quad (\text{only } \sigma_{tmin} < 0 \text{ buckl.})$$

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σ_{Sm} in the shell

Region of smaller wall thickness $t_s = 0.1875 \text{ in}$: (calculation case)

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

$$\sigma_{Sm} = -737.6 \text{ psi} \leq 2 \cdot 17952 \text{ psi} = 2 \cdot \sigma_{allS} \quad (4-7)$$

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

$$|-737.6 \text{ psi}| < \text{Min}(8493 \text{ psi}, 16994 \text{ psi})$$

ASME external pressure chart CS-2 $A = 0.001334$

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

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

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

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

ASME external pressure chart $A = \text{psi}$, psi)

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_s in the shell and σ_c in the channel

$$\sigma_s = |\sigma_{Sm}| + |\sigma_{sb}| = 23929 \text{ psi} \leq 1.5 \cdot \sigma_{allS}, S_{PSs} \text{ or } S_{PSs1}$$

$$\sigma_s = |-737.6 \text{ psi}| + |-23192 \text{ psi}| \leq 26929 \text{ psi}$$

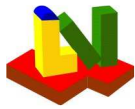
$$\sigma_c = |\sigma_{Cm}| + |\sigma_{Cb}| = 0 \text{ psi} \leq 1.5 \cdot \sigma_{allC} \text{ or } S_{PSc}$$

$$\sigma_c = |0 \text{ psi}| + |0 \text{ psi}| \leq 0 \text{ psi}$$

Minimum shell length with uniform thickness $l_{Sm} = 4.595 \text{ in}$

Minimum channel thickness with uniform thickness $l_{Cm} = \text{in}$

Strength condition UHX-13.5.11 is satisfied



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

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

Modulus of elasticity	elastic	Option 3
Shell	2.547e+7 psi	2.547e+7 psi
Channel	psi	psi

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

$\sigma_S =$ **23929** psi \leq 54515 psi $= S_{PSS}$

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

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

Geometric conditions:
valid

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

13.4(d) If: Tube sheet thickness= 3.062 in < 1 in

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

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance $c_2 > 0$) and without corrosion ($c_2 = 0$). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Equations

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

Allowable primary + secondary shell stress acc. UG-23(e):

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

$$54515 \text{ psi} = 3 \cdot 17952 \text{ psi} \quad \text{or } 2 \cdot 27257 \text{ psi}$$

(b) under the condition: SigZul not in the creep range:

$$T = 700 \text{ }^{\circ}\text{F} < 1000 \text{ }^{\circ}\text{F}$$

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

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.77 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 77.77 \text{ mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.4 \text{ mm} + 25.4 \text{ mm}) = 870.2 \text{ mm}$$

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

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

UHX-13.5.2 Step 2

$$K_s = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567115 \text{ N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6588 \text{ N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.89 \text{ mm}}{77.77 \text{ mm}} = 0.95$$

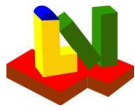
$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{31.75 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 0 \text{ mm}^2}{\pi \cdot (870.2 \text{ mm})^2}}} = 31.75 \text{ mm}$$

$$d^* = \text{Max} \left\{ \begin{matrix} d_1^* \\ d_2^* \end{matrix} \right\}$$

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho \right) \Leftrightarrow d_2^* = \left(25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm} \cdot \frac{175622 \text{ N/mm}^2}{175622 \text{ N/mm}^2} \cdot \frac{71.91 \text{ N/mm}^2}{123.8 \text{ N/mm}^2} \cdot 0.95 \right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75 \text{ mm} - 22.64 \text{ mm}}{31.75 \text{ mm}} = 0.2868$$



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Fixed Tubesheets - ASME BPVC VIII-1, UHX-13: 2021

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	b
Tubesheet integral with shell, gasketed with channel, flange extension		
Channel type (1=Cylinder, 2=Hemispherical)		1
Internal operating pressure shell side	P_s	150 psi
Internal operating pressure tube side	P_t	400 psi
Internal test pressure shell side	P_{sp}	psi
Internal test pressure tube side	P_{tp}	psi
Load case (1=operation, 2+3=test at 20°C, 4=other)		1

load case: operation

Calculation case per UHX-13.4(a):	(1-D1), (2-D2), (3-D3), (4-O4), (5-O1), (6-O2), (7-O3)	4
-----------------------------------	--	---

Differential thermal expansion only ($P_s=P_t=0$)

Tubesheet material	K02700-SA-516-70-Class:-Size:
Tube material	K01807-SA-214--Class:-Size:
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:

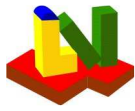
Operation	Tubesheet	Tubes	Shell
Temperature	700 °F	700 °F	700 °F
Thickness	3.062 in	0.083 in	0.1875 in
Outside diameter	40.5 in	1 in	35.13 in
Poisson's ratio	-	0.3	0.3
Allowance c_1	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in

Properties for the selected load case temperature

Strength operat.	17952 psi	10430 psi	17952 psi
Safety operation	1	1	1
Modulus of elasticity	2.547e+7 psi	2.547e+7 psi	2.547e+7 psi
Thermal expansion	7.586 1E-6/°F	7.586 1E-6/°F	7.586 1E-6/°F
Yield strength	27257 psi	18655 psi	27257 psi
Limit temperature	1000 °F	1000 °F	1000 °F
Allow. stress	17952 psi	10430 psi	17952 psi
Prim.+sec. str.	54515 psi		54515 psi

Properties for testing at 20°C

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



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1
Tube pattern	(1=Triangle, 2=Square)		1
Number of tubes		N_t	649
Expanded length of tube in tubesheet		$l_{t,x}$	2.909 in
Expanded length ratio $l_{t,x}/h$		ρ	0.95
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63 in
Perimeter of the outermost tubes	UHX-12.2	C_p	in
Total area enclosed by C_p	UHX-12.2	A_p	in ²
Tube pitch (center distance)		p	1.25 in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0 in ²
Depth of tube side pass partition groove		h_g	0 in
Tube length between inner tubesheet faces		L	161.9 in
Unsupported tube span for buckling		l	59 in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	1
Equivalent free buckling length $k \cdot l$		l_t	59 in
Bellows inside diameter at its convolution height		D_j	38.5 in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	11388 lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	1
Mean temperature along the shell length		T_{sm}	550 °F
Mean temperature along the tube length		T_{tm}	510 °F
Mean coefficient of thermal expansion of shell at T_{sm}		α_{sm}	7.3 1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}		α_{tm}	7.3 1E-6/°F

Material properties for mean operating temperature

UHX-13.8: Specification of values only for radial differential thermal expansion (type abc)

(Thermal expansion = 0 for ambient temperature=20°C=68°F)

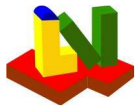
Tubesheet metal temperature at the rim	T'_r	68 °F
Channel metal temperature at the tubesheet	T'_c	68 °F
Shell metal temperature at the tubesheet	T'_s	68 °F
Mean coefficient of thermal expansion of		
Tubesheet at T'_r	α'_r	6.389 1E-6/°F
Channel at T'_c	α'_c	1E-6/°F
Shell unreinforced (for $l+l'=0$) at T'_s	α'_s	6.389 1E-6/°F
Shell reinforced acc. UHX-13.6 at T'_s	α'_s	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1	in
Bolt circle diameter	C	38.88 in
Number of bolts	n	68
Bolt root diameter	d_B	0.62 in
Total bolt area	A_b	20.53 in ²
Bolt material	G41400-SA-193-B7-Class:-Size:<=64	
Strength for operation	K_s	24946 psi
Strength for test	K_{sp}	24946 psi
Safety for operation	S_s	1
Safety for test	S_{sp}	1
Stress intensification factor for testing	F_s	1

Gasket

	Shell Type d		Channel Type b,c,d
Contact outside diameter	G_a	in	37.31 in
Contact inside diameter	G_i	in	in
Basic seating width	b_0	in	0.255 in
Gasket factor (Table 2-5.1)	m		3.75
Gasket seating pressure	Y	psi	7600 psi
Diameter of gasket force	G	in	36.81 in
Poisson's ratio	ν	0.3	0.3



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Results acc. UHX-9

Effective seating width	b	in
Gasket operating force	W	0 lbf
Total req. bolt root area	A _m	0 in ²
A _m < actual bolt area = 13245 mm ²		
Tubesheet flange thickness	h _r	0 in

Channel

0.2505 in
0 lbf
8.82 in ²
0.9888 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)
 Max. gasket seating force chan.=0.5(A_m+A_b)·K_{sp}/S_{sp}, App.2-5
 Stiffness ratio Bellows/Shell (=1 without bellows)
 Channel shell thickness without allowances
 Shell thickness without allowances
 Shell inside diameter corroded (type abc)

Y	(Y,N)
W	366091 lbf
J	0.003504
t _c	in
t _s	0.1875 in
D _s	34.76 in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T
 Tube material allowable stress basis at T
 Tube material allowable stress safety at T
 Basic ligament efficiency for shear
 Effective tube hole diameter
 Effective pitch
 Effective ligament efficiency for shear
 Effective depth of pass partition groove
 Equivalent radius of outer tube limit circle
 Radial channel dimension (type a: D_c/2, else: G_c/2)
 Radial shell dimension (type d: G_s/2, else: D_s/2)
 Ratio = a_c/a₀
 Ratio = a_s/a₀
 Parameter = 1-N_t·(0.5·d_aTUBE/a₀)²
 Parameter = 1-N_t·(0.5·d_iTUBE/a₀)²
 Type abc: Coefficients for shell pressure
 β_S 8.522 1/ft k_S 21840 lbf

E _{IT}	2.547e+7 psi
K _{IT}	12353 psi
S _{IT}	1
μ	0.2
d*	0.8915 in
p*	1.25 in
μ*	0.2868
h _g	0 in
a ₀	17.13 in
a _c	18.4 in
a _s	17.38 in
ρ _C	1.074
ρ _S	1.014
x _S	0.4471
x _t	0.6154
δ _S	0.198 mm ³ /N
λ _S	878699 psi

Step 2

Shell axial rigidity K_s or K_s*
 Tube axial rigidity
 Stiffness ratio K_s/(N_t·K_t)
 Stiffness ratio K_j/(K_s+K_j)

K _s	3238229 lbf/in
K _t	37618 lbf/in
K _{st}	0.1326
J	0.003504

Step 3

Effective modulus of el. tubesheet UHX-11.3
 Ratio of elasticity tubesheet
 effective Poisson's ratio tubesheet
 Parameter for table UHX-13.1
 Z_d 0.02465 Z_v 0.06434 Z_m 0.3718 Z_a 6.529 Z_w 0.06434

E*	6722551 psi
E*/E	0.2639
v*	0.3634
X _a	3.961
Z _w	0.06434

Step 4

Diameter ratio = A/D₀
 F 0.4868 Φ 0.6637
 Q_{z1} 2.854 Q_{z2} 6.881

K	1.182
Q ₁	-0.02266
U	13.76

UHX-13.5.5 Step 5, coefficients

Y(*) -0.04727 in ω_S 2.685 in²
 ω_C 0 in² ω_C* 9.639 in²

ω _S *	-2.654 in ²
Y _b	-0.06045

Results acc. UHX-13.8 Radial differential thermal expansion

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

T _c *	68 °F
P _w	0 psi

Step 6

P_s' 0 psi P_t' 0 psi
 P_w 165.2 psi P_{rim} 0 psi

P _y	-1252 psi
P _e	-0.5045 psi



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

UHX-13.5.7 Step 7

$$Q_2 = -2825 \text{ lbf} \quad Q_3 = 38.14 \quad F_m = 19.15$$

Strength condition for the tubesheet bending stress, case 4

$$\sigma = 6324 \text{ psi} < 1.5 \cdot \sigma_B = 17952 \text{ psi} \quad \text{case 1-3}$$

$$< S_{PS} = 54515 \text{ psi} \quad \text{case 4-7}$$

Step 8

Strength condition for the tubesheet shear stress:

$$\tau = \text{psi} \leq \text{MIN}[0.8\sigma_B; 0.533 S_y] = 14362 \text{ psi}$$

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

$$F_{tmin} = -143.8 \quad F_{tmax} = 305.1$$

$$x_{min} = 0 \quad x_{max} = 4.02$$

$$\sigma_{T,1} = -431.1 \text{ psi} \quad \sigma_{T,2} = 914.2 \text{ psi}$$

$$\sigma_{tmax} = 914.2 \text{ psi} \leq \sigma_T = 10430 \text{ psi} \quad \text{for calculation case 1-3}$$

$$\leq 2 \cdot \sigma_T = 20860 \text{ psi} \quad \text{for calculation case 4-7}$$

Tube weld force $W_t = 218.6 \text{ lbf} \leq W_{t,all} = 0 \text{ lbf}$
(only if weld thickness < tube thickness: enter $W_t, all > 0$ acc. UW-20)

$$r_t = 0.3255 \text{ in} \quad F_t = 181.2 \quad C_t = 1.25 \quad F_s = 164.2$$

$$|\sigma_{tmin}| = |-431.1 \text{ psi}| \leq S_{tb} = 6123 \text{ psi} \quad (\text{only } \sigma_{tmin} < 0 \text{ buckl.})$$

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σ_{Sm} in the shell

Region of smaller wall thickness $t_s = 0.1875 \text{ in}$: (calculation case)

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

$$\sigma_{Sm} = -22.6 \text{ psi} \leq 2 \cdot 17952 \text{ psi} = 2 \cdot \sigma_{allS} \quad (4-7)$$

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

$$|-22.6 \text{ psi}| < \text{Min}(8493 \text{ psi}, 16994 \text{ psi})$$

ASME external pressure chart CS-2 $A = 0.001334$

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

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

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

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

ASME external pressure chart $A = \text{psi}$

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_s in the shell and σ_c in the channel

$$\sigma_s = |\sigma_{Sm}| + |\sigma_{Sb}| = 7606 \text{ psi} \leq 1.5 \cdot \sigma_{allS}, S_{PSs} \text{ or } S_{PSs1}$$

$$\sigma_s = |-22.6 \text{ psi}| + |-7583 \text{ psi}| \leq 54515 \text{ psi}$$

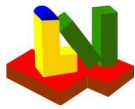
$$\sigma_c = |\sigma_{Cm}| + |\sigma_{Cb}| = 0 \text{ psi} \leq 1.5 \cdot \sigma_{allC} \text{ or } S_{PSc}$$

$$\sigma_c = 0 \text{ psi} + 0 \text{ psi} \leq 0 \text{ psi}$$

Minimum shell length with uniform thickness $l_{Sm} = 4.595 \text{ in}$

Minimum channel thickness with uniform thickness $l_{Cm} = \text{in}$

Strength condition UHX-13.5.11 is satisfied



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

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

Modulus of elasticity	elastic	Option 3
Shell	2.547e+7 psi	2.547e+7 psi
Channel	psi	psi

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

$$\sigma_S = \mathbf{7606} \text{ psi} \leq 54515 \text{ psi} = S_{PSs}$$

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

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

Geometric conditions:
valid

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

13.4(d) If: Tube sheet thickness= 3.062 in < 1 in
= Tube outside diameter, the tubesheet deformation must be considered.

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance $c_2 > 0$) and without corrosion ($c_2 = 0$). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Equations

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

Allowable primary + secondary shell stress acc. UG-23(e):

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

$$54515 \text{ psi} = 3 \cdot 17952 \text{ psi} \quad \text{or } 2 \cdot 27257 \text{ psi}$$

(b) under the condition: SigZul not in the creep range:

$$T = 700 \text{ }^{\circ}\text{F} < 1000 \text{ }^{\circ}\text{F}$$

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

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.77 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 77.77 \text{ mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.4 \text{ mm} + 25.4 \text{ mm}) = 870.2 \text{ mm}$$

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

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

UHX-13.5.2 Step 2

$$K_s = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567115 \text{ N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6588 \text{ N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.89 \text{ mm}}{77.77 \text{ mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{31.75 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 0 \text{ mm}^2}{\pi \cdot (870.2 \text{ mm})^2}}} = 31.75 \text{ mm}$$

$$d^* = \text{Max} \left\{ \begin{matrix} d_1^* \\ d_2^* \end{matrix} \right\}$$

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho \right) \Leftrightarrow d_2^* = \left(25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm} \cdot \frac{175622 \text{ N/mm}^2}{175622 \text{ N/mm}^2} \cdot \frac{71.91 \text{ N/mm}^2}{123.8 \text{ N/mm}^2} \cdot 0.95 \right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75 \text{ mm} - 22.64 \text{ mm}}{31.75 \text{ mm}} = 0.2868$$



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Fixed Tubesheets - ASME BPVC VIII-1, UHX-13: 2021

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	b
Tubesheet integral with shell, gasketed with channel, flange extension		
Channel type (1=Cylinder, 2=Hemispherical)		1
Internal operating pressure shell side	P_s	150 psi
Internal operating pressure tube side	P_t	400 psi
Internal test pressure shell side	P_{sp}	psi
Internal test pressure tube side	P_{tp}	psi
Load case (1=operation, 2+3=test at 20°C, 4=other)		1

load case: operation

Calculation case per UHX-13.4(a):	(1-D1), (2-D2), (3-D3), (4-O4), (5-O1), (6-O2), (7-O3)	5
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Tube side pressure only ($P_s=0$) with differential thermal expansion

Tubesheet material	K02700-SA-516-70-Class:-Size:
Tube material	K01807-SA-214--Class:-Size:
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:

Operation	Tubesheet	Tubes	Shell
Temperature	700 °F	700 °F	700 °F
Thickness	3.062 in	0.083 in	0.1875 in
Outside diameter	40.5 in	1 in	35.13 in
Poisson's ratio	-	0.3	0.3
Allowance c_1	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in

Properties for the selected load case temperature

Strength operat.	17952 psi	10430 psi	17952 psi
Safety operation	1	1	1
Modulus of elasticity	2.547e+7 psi	2.547e+7 psi	2.547e+7 psi
Thermal expansion	7.586 1E-6/°F	7.586 1E-6/°F	7.586 1E-6/°F
Yield strength	27257 psi	18655 psi	27257 psi
Limit temperature	1000 °F	1000 °F	1000 °F
Allow. stress	17952 psi	10430 psi	17952 psi
Prim.+sec. str.	54515 psi		54515 psi

Properties for testing at 20°C

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



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1
Tube pattern	(1=Triangle, 2=Square)		1
Number of tubes		N_t	649
Expanded length of tube in tubesheet		$l_{t,x}$	2.909 in
Expanded length ratio $l_{t,x}/h$		ρ	0.95
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63 in
Perimeter of the outermost tubes	UHX-12.2	C_p	in
Total area enclosed by C_p	UHX-12.2	A_p	in ²
Tube pitch (center distance)		p	1.25 in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0 in ²
Depth of tube side pass partition groove		h_g	0 in
Tube length between inner tubesheet faces		L	161.9 in
Unsupported tube span for buckling		l	59 in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	1
Equivalent free buckling length $k \cdot l$		l_t	59 in
Bellows inside diameter at its convolution height		D_j	38.5 in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	11388 lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	1
Mean temperature along the shell length		T_{sm}	550 °F
Mean temperature along the tube length		T_{tm}	510 °F
Mean coefficient of thermal expansion of shell at T_{sm}		α_{sm}	7.3 1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}		α_{tm}	7.3 1E-6/°F

Material properties for mean operating temperature

UHX-13.8: Specification of values only for radial differential thermal expansion (type abc)

(Thermal expansion = 0 for ambient temperature=20°C=68°F)

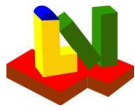
Tubesheet metal temperature at the rim	T'	68 °F
Channel metal temperature at the tubesheet	T'_c	68 °F
Shell metal temperature at the tubesheet	T'_s	68 °F
Mean coefficient of thermal expansion of		
Tubesheet at T'	α'	6.389 1E-6/°F
Channel at T'_c	α'_c	1E-6/°F
Shell unreinforced (for $l+l'=0$) at T'_s	α'_s	6.389 1E-6/°F
Shell reinforced acc. UHX-13.6 at T'_s	α'_s	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1	in
Bolt circle diameter	C	38.88 in
Number of bolts	n	68
Bolt root diameter	d_B	0.62 in
Total bolt area	A_b	20.53 in ²
Bolt material	G41400-SA-193-B7-Class:-Size:<=64	
Strength for operation	K_s	24946 psi
Strength for test	K_{sp}	24946 psi
Safety for operation	S_s	1
Safety for test	S_{sp}	1
Stress intensification factor for testing	F_s	1

Gasket

	Shell Type d		Channel Type b,c,d
Contact outside diameter	G_a	in	37.31 in
Contact inside diameter	G_i	in	in
Basic seating width	b_0	in	0.255 in
Gasket factor (Table 2-5.1)	m		3.75
Gasket seating pressure	Y	psi	7600 psi
Diameter of gasket force	G	in	36.81 in
Poisson's ratio	ν	0.3	0.3



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Results acc. UHX-9

	Shell	Channel
Effective seating width	b in	0.2505 in
Gasket operating force	W lbf	512301 lbf
Total req. bolt root area	A _m in ²	20.54 in ²
A _m < actual bolt area = 13245 mm ²		
Tubesheet flange thickness	h _r in	1.235 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(A _m +A _b)·K _{sp} /S _{sp} , App.2-5	W	512301 lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	0.003504
Channel shell thickness without allowances	t _c	in
Shell thickness without allowances	t _s	0.1875 in
Shell inside diameter corroded (type abc)	D _s	34.76 in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E _{IT}	2.547e+7 psi
Tube material allowable stress basis at T	K _{IT}	12353 psi
Tube material allowable stress safety at T	S _{IT}	1
Basic ligament efficiency for shear	μ	0.2
Effective tube hole diameter	d*	0.8915 in
Effective pitch	p*	1.25 in
Effective ligament efficiency for shear	μ*	0.2868
Effective depth of pass partition groove	h _g	0 in
Equivalent radius of outer tube limit circle	a ₀	17.13 in
Radial channel dimension (type a: D _c /2, else: G _c /2)	a _c	18.4 in
Radial shell dimension (type d: G _s /2, else: D _s /2)	a _s	17.38 in
Ratio = a _c /a ₀	ρ _C	1.074
Ratio = a _s /a ₀	ρ _S	1.014
Parameter = 1-N _t ·(0.5·d _a TUBE/a ₀) ²	x _s	0.4471
Parameter = 1-N _t ·(0.5·d _i TUBE/a ₀) ²	x _t	0.6154
Type abc: Coefficients for shell pressure	δ _S	0.198 mm ³ /N
β _S 8.522 1/ft	k _S 21840 lbf	λ _S 878699 psi

Step 2

Shell axial rigidity K _s or K _s *	K _s	3238229 lbf/in
Tube axial rigidity	K _t	37618 lbf/in
Stiffness ratio K _s /(N _t ·K _t)	K _{st}	0.1326
Stiffness ratio K _j /(K _s +K _j)	J	0.003504

Step 3

Effective modulus of el. tubesheet	UHX-11.3				E*	6722551	psi
Ratio of elasticity tubesheet					E*/E	0.2639	
effective Poisson's ratio tubesheet					v*	0.3634	
Parameter for table UHX-13.1					X _a	3.961	
Z _d	0.02465	Z _v	0.06434	Z _m	0.3718	Z _a	6.529
						Z _w	0.06434

Step 4

Diameter ratio = A/D ₀		K	1.182
F 0.4868	Φ 0.6637	Q ₁	-0.02266
Q _{z1} 2.854	Q _{z2} 6.881	U	13.76

UHX-13.5.5 Step 5, coefficients

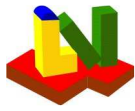
Y(*) -0.04727 in	ω _S 2.685 in ²	ω _S *	-2.654 in ²
ω _C 0 in ²	ω _C *	9.639 in ²	γ _b -0.06045

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 _w	0 psi

Step 6

P _s ' 0 psi	P _t ' 860900 psi	P _y	-1252 psi
P _w 231.2 psi	P _{rim} 180.8 psi	P _e	-400 psi



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

UHX-13.5.7 Step 7

$$Q_2 = -7046 \text{ lbf} \quad Q_3 = 0.09739 \quad F_m = 0.09749$$

Strength condition for the tubesheet bending stress, case 5

$$\sigma = 25532 \text{ psi} < 1.5 \cdot \sigma_B = 17952 \text{ psi} \quad \text{case 1-3}$$

$$< S_{PS} = 54515 \text{ psi} \quad \text{case 4-7}$$

Step 8

Strength condition for the tubesheet shear stress:

$$\tau = \text{psi} \leq \text{MIN}[0.8\sigma_B; 0.533 S_y] = 14362 \text{ psi}$$

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

$$F_{tmin} = -1.081 \quad F_{tmax} = 3.805$$

$$x_{min} = 0 \quad x_{max} = 4.02$$

$$\sigma_{T,1} = -4031 \text{ psi} \quad \sigma_{T,2} = 7579 \text{ psi}$$

$$\sigma_{tmax} = 7579 \text{ psi} \leq \sigma_T = 10430 \text{ psi} \quad \text{for calculation case 1-3}$$

$$\leq 2 \cdot \sigma_T = 20860 \text{ psi} \quad \text{for calculation case 4-7}$$

Tube weld force $W_t = 1812 \text{ lbf} \leq W_{t,all} = 0 \text{ lbf}$
(only if weld thickness < tube thickness: enter $W_t, all > 0$ acc. UW-20)

$$r_t = 0.3255 \text{ in} \quad F_t = 181.2 \quad C_t = 1.348 \quad F_s = 164.2$$

$$|\sigma_{tmin}| = -4031 \text{ psi} \leq S_{tb} = 5679 \text{ psi} \quad (\text{only } \sigma_{tmin} < 0 \text{ buckl.})$$

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σ_{Sm} in the shell

Region of smaller wall thickness $t_s = 0.1875 \text{ in}$: (calculation case)

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

$$\sigma_{Sm} = 0.05837 \text{ psi} \leq 2 \cdot 17952 \text{ psi} = 2 \cdot \sigma_{allS} \quad (4-7)$$

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

$$0.05837 \text{ psi} < \text{Min}(8493 \text{ psi}, 16994 \text{ psi})$$

ASME external pressure chart CS-2 $A = 0.001334$

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

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

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

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

ASME external pressure chart $A = \text{psi}$

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_s in the shell and σ_c in the channel

$$\sigma_s = |\sigma_{Sm}| + |\sigma_{Sb}| = 42439 \text{ psi} \leq 1.5 \cdot \sigma_{allS}, S_{PSs} \text{ or } S_{PSs1}$$

$$\sigma_s = 0.05837 \text{ psi} + -42439 \text{ psi} \leq 54515 \text{ psi}$$

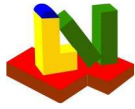
$$\sigma_c = |\sigma_{Cm}| + |\sigma_{Cb}| = 0 \text{ psi} \leq 1.5 \cdot \sigma_{allC} \text{ or } S_{PSc}$$

$$\sigma_c = 0 \text{ psi} + 0 \text{ psi} \leq 0 \text{ psi}$$

Minimum shell length with uniform thickness $l_{Sm} = 4.595 \text{ in}$

Minimum channel thickness with uniform thickness $l_{Cm} = \text{in}$

Strength condition UHX-13.5.11 is satisfied



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

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

Modulus of elasticity	elastic	Option 3
Shell	2.547e+7 psi	2.547e+7 psi
Channel	psi	psi

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

$\sigma_S =$ **42439** psi \leq 54515 psi $= S_{PSS}$

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

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

Geometric conditions:
valid

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

13.4(d) If: Tube sheet thickness= 3.062 in $<$ 1 in

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

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance $c_2 > 0$) and without corrosion ($c_2 = 0$). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Equations

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

Allowable primary + secondary shell stress acc. UG-23(e):

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

$$54515 \text{ psi} = 3 \cdot 17952 \text{ psi} \quad \text{or } 2 \cdot 27257 \text{ psi}$$

(b) under the condition: SigZul not in the creep range:

$$T = 700 \text{ }^{\circ}\text{F} < 1000 \text{ }^{\circ}\text{F}$$

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

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.77 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 77.77 \text{ mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.4 \text{ mm} + 25.4 \text{ mm}) = 870.2 \text{ mm}$$

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

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

UHX-13.5.2 Step 2

$$K_s = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567115 \text{ N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6588 \text{ N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.89 \text{ mm}}{77.77 \text{ mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{31.75 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 0 \text{ mm}^2}{\pi \cdot (870.2 \text{ mm})^2}}} = 31.75 \text{ mm}$$

$$d^* = \text{Max} \left\{ \begin{matrix} d_1^* \\ d_2^* \end{matrix} \right\}$$

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho \right) \Leftrightarrow d_2^* = \left(25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm} \cdot \frac{175622 \text{ N/mm}^2}{175622 \text{ N/mm}^2} \cdot \frac{71.91 \text{ N/mm}^2}{123.8 \text{ N/mm}^2} \cdot 0.95 \right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75 \text{ mm} - 22.64 \text{ mm}}{31.75 \text{ mm}} = 0.2868$$



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Fixed Tubesheets - ASME BPVC VIII-1, UHX-13: 2021

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	b
Tubesheet integral with shell, gasketed with channel, flange extension		
Channel type (1=Cylinder, 2=Hemispherical)		1
Internal operating pressure shell side	P_s	150 psi
Internal operating pressure tube side	P_t	400 psi
Internal test pressure shell side	P_{sp}	psi
Internal test pressure tube side	P_{tp}	psi
Load case (1=operation, 2+3=test at 20°C, 4=other)		1

load case: operation

Calculation case per UHX-13.4(a):	(1-D1), (2-D2), (3-D3), (4-O4), (5-O1), (6-O2), (7-O3)	6
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Shell side pressure only ($P_t=0$) with differential thermal expansion

Tubesheet material	K02700-SA-516-70-Class:-Size:
Tube material	K01807-SA-214--Class:-Size:
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:

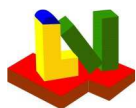
Operation	Tubesheet	Tubes	Shell
Temperature	700 °F	700 °F	700 °F
Thickness	3.062 in	0.083 in	0.1875 in
Outside diameter	40.5 in	1 in	35.13 in
Poisson's ratio	-	0.3	0.3
Allowance c_1	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in

Properties for the selected load case temperature

Strength operat.	17952 psi	10430 psi	17952 psi
Safety operation	1	1	1
Modulus of elasticity	2.547e+7 psi	2.547e+7 psi	2.547e+7 psi
Thermal expansion	7.586 1E-6/°F	7.586 1E-6/°F	7.586 1E-6/°F
Yield strength	27257 psi	18655 psi	27257 psi
Limit temperature	1000 °F	1000 °F	1000 °F
Allow. stress	17952 psi	10430 psi	17952 psi
Prim.+sec. str.	54515 psi		54515 psi

Properties for testing at 20°C

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



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1
Tube pattern	(1=Triangle, 2=Square)		1
Number of tubes		N_t	649
Expanded length of tube in tubesheet		$l_{t,x}$	2.909 in
Expanded length ratio $l_{t,x}/h$		ρ	0.95
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63 in
Perimeter of the outermost tubes	UHX-12.2	C_p	in
Total area enclosed by C_p	UHX-12.2	A_p	in ²
Tube pitch (center distance)		p	1.25 in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0 in ²
Depth of tube side pass partition groove		h_g	0 in
Tube length between inner tubesheet faces		L	161.9 in
Unsupported tube span for buckling		l	59 in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	1
Equivalent free buckling length $k \cdot l$		l_t	59 in
Bellows inside diameter at its convolution height		D_j	38.5 in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	11388 lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	1
Mean temperature along the shell length		T_{sm}	550 °F
Mean temperature along the tube length		T_{tm}	510 °F
Mean coefficient of thermal expansion of shell at T_{sm}		α_{sm}	7.3 1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}		α_{tm}	7.3 1E-6/°F

Material properties for mean operating temperature

UHX-13.8: Specification of values only for radial differential thermal expansion (type abc)

(Thermal expansion = 0 for ambient temperature=20°C=68°F)

Tubesheet metal temperature at the rim	T'_r	68 °F
Channel metal temperature at the tubesheet	T'_c	68 °F
Shell metal temperature at the tubesheet	T'_s	68 °F
Mean coefficient of thermal expansion of		
Tubesheet at T'_r	α'_r	6.389 1E-6/°F
Channel at T'_c	α'_c	1E-6/°F
Shell unreinforced (for $l+l'=0$) at T'_s	α'_s	6.389 1E-6/°F
Shell reinforced acc. UHX-13.6 at T'_s	α'_s	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1	in
Bolt circle diameter	C	38.88 in
Number of bolts	n	68
Bolt root diameter	d_B	0.62 in
Total bolt area	A_b	20.53 in ²
Bolt material	G41400-SA-193-B7-Class:-Size:<=64	
Strength for operation	K_s	25000 psi
Strength for test	K_{sp}	25000 psi
Safety for operation	S_s	1
Safety for test	S_{sp}	1
Stress intensification factor for testing	F_s	1

Gasket

	Shell Type d	Channel Type b,c,d
Contact outside diameter	G_a	37.31 in
Contact inside diameter	G_i	in
Basic seating width	b_0	0.255 in
Gasket factor (Table 2-5.1)	m	3.75
Gasket seating pressure	Y	7600 psi
Diameter of gasket force	G	36.81 in
Poisson's ratio	ν	0.3



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Results acc. UHX-9

Effective seating width
Gasket operating force
Total req. bolt root area
 $A_m < \text{actual bolt area} = 13245 \text{ mm}^2$
Tubesheet flange thickness

Shell

b in
 W lbf
 A_m in²
 h_r in

Channel

0.2505 in
0 lbf
8.801 in²
0.9895 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)
Max. gasket seating force chan.= $0.5(A_m+Ab) \cdot K_{sp}/S_{sp}, \text{App.2-5}$
Stiffness ratio Bellows/Shell (=1 without bellows)
Channel shell thickness without allowances
Shell thickness without allowances
Shell inside diameter corroded (type abc)

Y (Y,N)
 W **366642** lbf
 J **0.003504**
 t_c in
 t_s **0.1875** in
 D_s **34.76** in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T
Tube material allowable stress basis at T
Tube material allowable stress safety at T
Basic ligament efficiency for shear
Effective tube hole diameter
Effective pitch
Effective ligament efficiency for shear
Effective depth of pass partition groove
Equivalent radius of outer tube limit circle
Radial channel dimension (type a: $D_c/2$, else: $G_c/2$)
Radial shell dimension (type d: $G_s/2$, else: $D_s/2$)
Ratio = a_c/a_0
Ratio = a_s/a_0
Parameter = $1-N_t \cdot (0.5 \cdot d_a \text{TUBE}/a_0)^2$
Parameter = $1-N_t \cdot (0.5 \cdot d_i \text{TUBE}/a_0)^2$
Type abc: Coefficients for shell pressure
 β_s **8.522** 1/ft
 k_s **21840** lbf

E_{IT} 2.547e+7 psi
 K_{IT} 12353 psi
 S_{IT} 1
 μ **0.2**
 d^* **0.8915** in
 p^* **1.25** in
 μ^* **0.2868**
 h_g' 0 in
 a_0 **17.13** in
 a_c **18.4** in
 a_s **17.38** in
 ρ_c **1.074**
 ρ_s **1.014**
 x_s **0.4471**
 x_t **0.6154**
 δ_s **0.198** mm³/N
 λ_s **878699** psi

Step 2

Shell axial rigidity K_s or K_s^*
Tube axial rigidity
Stiffness ratio $K_s/(N_t \cdot K_t)$
Stiffness ratio $K_j/(K_s+K_j)$

K_s **3238229** lbf/in
 K_t **37618** lbf/in
 K_{st} **0.1326**
 J **0.003504**

Step 3

Effective modulus of el. tubesheet UHX-11.3
Ratio of elasticity tubesheet
effective Poisson's ratio tubesheet
Parameter for table UHX-13.1
 Z_d **0.02465** Z_v **0.06434** Z_m **0.3718** Z_a **6.529** Z_w **0.06434**

E^* **6722551** psi
 E^*/E **0.2639**
 v^* **0.3634**
 X_a **3.961**
 Z_w **0.06434**

Step 4

Diameter ratio = A/D_0
 F **0.4868**
 Q_{z1} **2.854**

Φ **0.6637**
 Q_{z2} **6.881**

K **1.182**
 Q_1 **-0.02266**
 U **13.76**

UHX-13.5.5 Step 5, coefficients

$\gamma(^*)$ **-0.04727** in
 ω_c **0** in²

ω_s **2.685** in²
 ω_c^* **9.639** in²

ω_s^* **-2.654** in²
 γ_b **-0.06045**

Results acc. UHX-13.8 Radial differential thermal expansion

T_r **68** °F
 P_s^* **0** psi

T_s^* **68** °F
 P_c^* **0** psi

T_c^* **68** °F
 P_w **0** psi

Step 6

P_s' **-46159** psi
 P_w **165.4** psi

P_t' **0** psi
 P_{rim} **18.67** psi

P_y **-1252** psi
 P_e **-21.92** psi



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

UHX-13.5.7 Step 7

$$Q_2 = -3149 \text{ lbf} \quad Q_3 = 0.9563 \quad F_m = 0.5009$$

Strength condition for the tubesheet bending stress, case 6

$$\sigma = 7190 \text{ psi} < 1.5 \cdot \sigma_B = 17952 \text{ psi} \quad \text{case 1-3}$$

$$< S_{PS} = 54515 \text{ psi} \quad \text{case 4-7}$$

Step 8

Strength condition for the tubesheet shear stress:

$$\tau = \text{psi} \leq \text{MIN}[0.8\sigma_B; 0.533 S_y] = 14362 \text{ psi}$$

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

$$F_{tmin} = -4.254 \quad F_{tmax} = 10.61$$

$$x_{min} = 0 \quad x_{max} = 3.971$$

$$\sigma_{T,1} = -155.6 \text{ psi} \quad \sigma_{T,2} = 1779 \text{ psi}$$

$$\sigma_{tmax} = 1779 \text{ psi} \leq \sigma_T = 10430 \text{ psi} \quad \text{for calculation case 1-3}$$

$$\leq 2 \cdot \sigma_T = 20860 \text{ psi} \quad \text{for calculation case 4-7}$$

Tube weld force $W_t = 425.5 \text{ lbf} \leq W_{t,all} = 0 \text{ lbf}$
(only if weld thickness < tube thickness: enter $W_t, all > 0$ acc. UW-20)

$$r_t = 0.3255 \text{ in} \quad F_t = 181.2 \quad C_t = 1.25 \quad F_s = 164.2$$

$$|\sigma_{tmin}| = |-155.6 \text{ psi}| \leq S_{tb} = 6123 \text{ psi} \quad (\text{only } \sigma_{tmin} < 0 \text{ buckl.})$$

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σ_{Sm} in the shell

Region of smaller wall thickness $t_s = 0.1875 \text{ in}$: (calculation case)

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

$$\sigma_{Sm} = -786.3 \text{ psi} \leq 2 \cdot 17952 \text{ psi} = 2 \cdot \sigma_{allS} \quad (4-7)$$

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

$$|-786.3 \text{ psi}| < \text{Min}(8493 \text{ psi}, 16994 \text{ psi})$$

ASME external pressure chart CS-2 $A = 0.001334$

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

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

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

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

ASME external pressure chart $A = \text{psi}$

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_s in the shell and σ_c in the channel

$$\sigma_s = |\sigma_{Sm}| + |\sigma_{Sb}| = 12415 \text{ psi} \leq 1.5 \cdot \sigma_{allS}, S_{PSs} \text{ or } S_{PSs1}$$

$$|-786.3 \text{ psi}| + |11629 \text{ psi}| \leq 54515 \text{ psi}$$

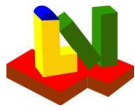
$$\sigma_c = |\sigma_{Cm}| + |\sigma_{Cb}| = 0 \text{ psi} \leq 1.5 \cdot \sigma_{allC} \text{ or } S_{PSc}$$

$$0 \text{ psi} + 0 \text{ psi} \leq 0 \text{ psi}$$

Minimum shell length with uniform thickness $l_{Sm} = 4.595 \text{ in}$

Minimum channel thickness with uniform thickness $l_{Cm} = \text{in}$

Strength condition UHX-13.5.11 is satisfied



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

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

Modulus of elasticity	elastic	Option 3
Shell	2.547e+7 psi	2.547e+7 psi
Channel	psi	psi

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

$\sigma_S =$ **12415** psi \leq **54515** psi $= S_{PSS}$

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

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

Geometric conditions:
valid

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

13.4(d) If: Tube sheet thickness= 3.062 in < 1 in

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

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance $c_2 > 0$) and without corrosion ($c_2 = 0$). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Equations

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

Allowable primary + secondary shell stress acc. UG-23(e):

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

$$54515 \text{ psi} = 3 \cdot 17952 \text{ psi} \quad \text{or } 2 \cdot 27257 \text{ psi}$$

(b) under the condition: SigZul not in the creep range:

$$T = 700 \text{ }^{\circ}\text{F} < 1000 \text{ }^{\circ}\text{F}$$

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

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.77 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 77.77 \text{ mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.4 \text{ mm} + 25.4 \text{ mm}) = 870.2 \text{ mm}$$

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

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

UHX-13.5.2 Step 2

$$K_s = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567115 \text{ N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6588 \text{ N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.89 \text{ mm}}{77.77 \text{ mm}} = 0.95$$

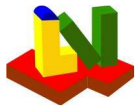
$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{31.75 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 0 \text{ mm}^2}{\pi \cdot (870.2 \text{ mm})^2}}} = 31.75 \text{ mm}$$

$$d^* = \text{Max} \left\{ \begin{matrix} d_1^* \\ d_2^* \end{matrix} \right\}$$

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho \right) \Leftrightarrow d_2^* = \left(25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm} \cdot \frac{175622 \text{ N/mm}^2}{175622 \text{ N/mm}^2} \cdot \frac{71.91 \text{ N/mm}^2}{123.8 \text{ N/mm}^2} \cdot 0.95 \right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75 \text{ mm} - 22.64 \text{ mm}}{31.75 \text{ mm}} = 0.2868$$



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Fixed Tubesheets - ASME BPVC VIII-1, UHX-13: 2021

Fixed tubesheets according to ASME-UHX-13

Configuration of the tubesheet (a, b, c, d)	Type	b
Tubesheet integral with shell, gasketed with channel, flange extension		
Channel type (1=Cylinder, 2=Hemispherical)		1
Internal operating pressure shell side	P_s	150 psi
Internal operating pressure tube side	P_t	400 psi
Internal test pressure shell side	P_{sp}	psi
Internal test pressure tube side	P_{tp}	psi
Load case (1=operation, 2+3=test at 20°C, 4=other)		1
load case: operation		
Calculation case per UHX-13.4(a): (1-D1), (2-D2), (3-D3), (4-O4), (5-O1), (6-O2), (7-O3)		7

Tube and shell side pressure acting with differential thermal expansion

Tubesheet material	K02700-SA-516-70-Class:-Size:
Tube material	K01807-SA-214--Class:-Size:
Shell material (Type abc)	K02700-SA-516-70-Class:-Size:

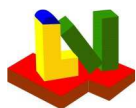
Operation	Tubesheet	Tubes	Shell
Temperature	700 °F	700 °F	700 °F
Thickness	3.062 in	0.083 in	0.1875 in
Outside diameter	40.5 in	1 in	35.13 in
Poisson's ratio	-	0.3	0.3
Allowance c_1	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in

Properties for the selected load case temperature

Strength operat.	17952 psi	10430 psi	17952 psi
Safety operation	1	1	1
Modulus of elasticity	2.547e+7 psi	2.547e+7 psi	2.547e+7 psi
Thermal expansion	7.586 1E-6/°F	7.586 1E-6/°F	7.586 1E-6/°F
Yield strength	27257 psi	18655 psi	27257 psi
Limit temperature	1000 °F	1000 °F	1000 °F
Allow. stress	17952 psi	10430 psi	17952 psi
Prim.+sec. str.	54515 psi		54515 psi

Properties for testing at 20°C

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



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Additional specifications for the geometry and loading

Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		1
Tube pattern	(1=Triangle, 2=Square)		1
Number of tubes		N_t	649
Expanded length of tube in tubesheet		$l_{t,x}$	2.909 in
Expanded length ratio $l_{t,x}/h$		ρ	0.95
Radius to outermost tube hole center	UHX-11.1(a)	r_{0T}	16.63 in
Perimeter of the outermost tubes	UHX-12.2	C_p	in
Total area enclosed by C_p	UHX-12.2	A_p	in ²
Tube pitch (center distance)		p	1.25 in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	0 in ²
Depth of tube side pass partition groove		h_g	0 in
Tube length between inner tubesheet faces		L	161.9 in
Unsupported tube span for buckling		l	59 in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	1
Equivalent free buckling length $k \cdot l$		l_t	59 in
Bellows inside diameter at its convolution height		D_j	38.5 in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	11388 lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	1
Mean temperature along the shell length		T_{sm}	550 °F
Mean temperature along the tube length		T_{tm}	510 °F
Mean coefficient of thermal expansion of shell at T_{sm}		α_{sm}	7.3 1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}		α_{tm}	7.3 1E-6/°F

Material properties for mean operating temperature

UHX-13.8: Specification of values only for radial differential thermal expansion (type abc)

(Thermal expansion = 0 for ambient temperature=20°C=68°F)

Tubesheet metal temperature at the rim	T'_r	68 °F
Channel metal temperature at the tubesheet	T'_c	68 °F
Shell metal temperature at the tubesheet	T'_s	68 °F
Mean coefficient of thermal expansion of		
Tubesheet at T'_r	α'_r	6.389 1E-6/°F
Channel at T'_c	α'_c	1E-6/°F
Shell unreinforced (for $l+l'=0$) at T'_s	α'_s	6.389 1E-6/°F
Shell reinforced acc. UHX-13.6 at T'_s	α'_s	1E-6/°F

Flange (Type bcd):

Mean contact diameter tubesheet-flange (type c)	G_1	in
Bolt circle diameter	C	38.88 in
Number of bolts	n	68
Bolt root diameter	d_B	0.62 in
Total bolt area	A_b	20.53 in ²
Bolt material	G41400-SA-193-B7-Class:-Size:<=64	
Strength for operation	K_s	24946 psi
Strength for test	K_{sp}	24946 psi
Safety for operation	S_s	1
Safety for test	S_{sp}	1
Stress intensification factor for testing	F_s	1

Gasket

	Shell Type d		Channel Type b,c,d
Contact outside diameter	G_a	in	37.31 in
Contact inside diameter	G_i	in	in
Basic seating width	b_0	in	0.255 in
Gasket factor (Table 2-5.1)	m		3.75
Gasket seating pressure	Y	psi	7600 psi
Diameter of gasket force	G	in	36.81 in
Poisson's ratio	ν	0.3	0.3



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Results acc. UHX-9

	Shell	Channel
Effective seating width	b in	0.2505 in
Gasket operating force	W lbf	512301 lbf
Total req. bolt root area	A_m in ²	20.54 in ²
$A_m < \text{actual bolt area} = 13245 \text{ mm}^2$		
Tubesheet flange thickness	h_r in	1.235 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(A_m+A_b)· K_{sp}/S_{sp} , App.2-5	W	512301 lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	0.003504
Channel shell thickness without allowances	t_c	in
Shell thickness without allowances	t_s	0.1875 in
Shell inside diameter corroded (type abc)	D_s	34.76 in

Step 1 acc. UHX 11.5+13.5

Tube material mod. of elast. at tubesheet temperature T	E_{iT}	2.547e+7 psi
Tube material allowable stress basis at T	K_{iT}	12353 psi
Tube material allowable stress safety at T	S_{iT}	1
Basic ligament efficiency for shear	μ	0.2
Effective tube hole diameter	d^*	0.8915 in
Effective pitch	p^*	1.25 in
Effective ligament efficiency for shear	μ^*	0.2868
Effective depth of pass partition groove	h_g'	0 in
Equivalent radius of outer tube limit circle	a_0	17.13 in
Radial channel dimension (type a: $D_c/2$, else: $G_c/2$)	a_c	18.4 in
Radial shell dimension (type d: $G_s/2$, else: $D_s/2$)	a_s	17.38 in
Ratio = a_c/a_0	ρ_c	1.074
Ratio = a_s/a_0	ρ_s	1.014
Parameter = $1-N_t \cdot (0.5 \cdot d_a \text{TUBE}/a_0)^2$	x_s	0.4471
Parameter = $1-N_t \cdot (0.5 \cdot d_i \text{TUBE}/a_0)^2$	x_t	0.6154
Type abc: Coefficients for shell pressure	δ_s	0.198 mm ³ /N
β_s 8.522 1/ft	k_s 21840 lbf	λ_s 878699 psi

Step 2

Shell axial rigidity K_s or K_s^*	K_s	3238229 lbf/in
Tube axial rigidity	K_t	37618 lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st}	0.1326
Stiffness ratio $K_j/(K_s+K_j)$	J	0.003504

Step 3

Effective modulus of el. tubesheet	UHX-11.3	E^*	6722551 psi
Ratio of elasticity tubesheet		E^*/E	0.2639
effective Poisson's ratio tubesheet		ν^*	0.3634
Parameter for table UHX-13.1		X_a	3.961
Z_d 0.02465 Z_v 0.06434 Z_m 0.3718 Z_a 6.529		Z_w	0.06434

Step 4

Diameter ratio = A/D_0		K	1.182
F 0.4868	Φ 0.6637	Q_1	-0.02266
Q_{z1} 2.854	Q_{z2} 6.881	U	13.76

UHX-13.5.5 Step 5, coefficients

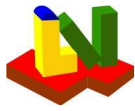
$\gamma(^*)$ -0.04727 in	ω_s 2.685 in ²	ω_s^* -2.654 in ²
ω_c 0 in ²	ω_c^* 9.639 in ²	γ_b -0.06045

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_w 0 psi

Step 6

P_s' -46159 psi	P_t' 860900 psi	P_y -1252 psi
P_w 231.2 psi	P_{rim} 199.5 psi	P_e -421.4 psi



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

UHX-13.5.7 Step 7

$$Q_2 = -7365 \text{ lbf} \quad Q_3 = 0.09646 \quad F_m = 0.09712$$

Strength condition for the tubesheet bending stress, case 1-3

$$\sigma = 26796 \text{ psi} < 1.5 \cdot \sigma_B = 17952 \text{ psi}$$

case 4-7

$$< S_{PS} = 54515 \text{ psi}$$

Step 8

Strength condition for the tubesheet shear stress:

$$\tau = \text{psi} \leq \text{MIN}[0.8\sigma_B; 0.533 S_y] = 14362 \text{ psi}$$

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

$$F_{tmin} = -1.078 \quad F_{tmax} = 3.797$$

$$x_{min} = 0 \quad x_{max} = 4.02$$

$$\sigma_{T,1} = -3762 \text{ psi} \quad \sigma_{T,2} = 8442 \text{ psi}$$

$$\sigma_{tmax} = 8442 \text{ psi} \leq \sigma_T = 10430 \text{ psi} \quad \text{for calculation case 1-3}$$

$$\leq 2 \cdot \sigma_T = 20860 \text{ psi} \quad \text{for calculation case 4-7}$$

Tube weld force $W_t = 2019 \text{ lbf} \leq W_{t,all} = 0 \text{ lbf}$
(only if weld thickness < tube thickness: enter $W_t, all > 0$ acc. UW-20)

$$r_t = 0.3255 \text{ in} \quad F_t = 181.2 \quad C_t = 1.351 \quad F_s = 164.2$$

$$|\sigma_{tmin}| = -3762 \text{ psi} \leq S_{tb} = 5664 \text{ psi} \quad (\text{only } \sigma_{tmin} < 0 \text{ buckl.})$$

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σ_{Sm} in the shell

Region of smaller wall thickness $t_s = 0.1875 \text{ in}$: (calculation case)

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

$$\sigma_{Sm} = -763.6 \text{ psi} \leq 2 \cdot 17952 \text{ psi} = 2 \cdot \sigma_{allS} \quad (4-7)$$

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

$$-763.6 \text{ psi} < \text{Min}(8493 \text{ psi}, 16994 \text{ psi})$$

ASME external pressure chart CS-2 $A = 0.001334$

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

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

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

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

ASME external pressure chart $A = \text{psi}$

Strength condition 13.5.10 satisfied

Step 11: Absolute value of stresses σ_s in the shell and σ_c in the channel

$$\sigma_s = |\sigma_{Sm}| + |\sigma_{Sb}| = 23980 \text{ psi} \leq 1.5 \cdot \sigma_{allS}, S_{PSs} \text{ or } S_{PSs1}$$

$$\sigma_s = -763.6 \text{ psi} + -23216 \text{ psi} \leq 54515 \text{ psi}$$

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

$$\sigma_c = 0 \text{ psi} + 0 \text{ psi} \leq 0 \text{ psi}$$

Minimum shell length with uniform thickness $l_{Sm} = 4.595 \text{ in}$

Minimum channel thickness with uniform thickness $l_{Cm} = \text{in}$

Strength condition UHX-13.5.11 is satisfied



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

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

Modulus of elasticity	elastic	Option 3
Shell	2.547e+7 psi	2.547e+7 psi
Channel	psi	psi

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

$\sigma_S =$ **23980** psi \leq 54515 psi $= S_{PSS}$

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

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

Geometric conditions:
valid

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

13.4(d) If: Tube sheet thickness= 3.062 in < 1 in
= Tube outside diameter, the tubesheet deformation must be considered.

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance $c_2 > 0$) and without corrosion ($c_2 = 0$). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).



ASME BPVC VIII-1 2021

Example E4.18.5 PTB-4-2021

Equations

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

Allowable primary + secondary shell stress acc. UG-23(e):

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

$$54515 \text{ psi} = 3 \cdot 17952 \text{ psi} \quad \text{or } 2 \cdot 27257 \text{ psi}$$

(b) under the condition: SigZul not in the creep range:

$$T = 700 \text{ }^{\circ}\text{F} < 1000 \text{ }^{\circ}\text{F}$$

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

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

$$h = t_{vB} - c_{1B} - c_{2B} = 77.77 \text{ mm} - 0 \text{ mm} - 0 \text{ mm} = 77.77 \text{ mm}$$

UHX-13.5.1 Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (422.4 \text{ mm} + 25.4 \text{ mm}) = 870.2 \text{ mm}$$

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

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

UHX-13.5.2 Step 2

$$K_s = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 567115 \text{ N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 6588 \text{ N/mm}$$

UHX-13.5.3 Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{73.89 \text{ mm}}{77.77 \text{ mm}} = 0.95$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{31.75 \text{ mm}}{\sqrt{1 - \frac{4 \cdot 0 \text{ mm}^2}{\pi \cdot (870.2 \text{ mm})^2}}} = 31.75 \text{ mm}$$

$$d^* = \text{Max} \left\{ \begin{matrix} d_1^* \\ d_2^* \end{matrix} \right\}$$

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho \right) \Leftrightarrow d_2^* = \left(25.4 \text{ mm} - 2 \cdot 2.108 \text{ mm} \cdot \frac{175622 \text{ N/mm}^2}{175622 \text{ N/mm}^2} \cdot \frac{71.91 \text{ N/mm}^2}{123.8 \text{ N/mm}^2} \cdot 0.95 \right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75 \text{ mm} - 22.64 \text{ mm}}{31.75 \text{ mm}} = 0.2868$$