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Layout

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

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

Example 4.18.5 - 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/lbf	0,0	in^3/lbf	**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	psi	879437,0	psi	**0,08%**
Shell axial rigidity	K_s	567115,4	N/mm	3238228,9	lbf/in	3241928,0	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	**v***	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%**

	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 [%]
	γ(*)							
	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%**
		Pt	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%**
		Pt	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%**
		Pt	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%**

Summary table for Step 5 -Operation Condition									
Loading Case									
1	**P_s**	0,0	Mpa	0,0	psi	0,0	psi	**0,00%**
	Pt	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%**
	Pt	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%**
	Pt	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%**
	Pt	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								
		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	860906,2	psi	862002,0	psi	**0,13%**
	P_γ		Mpa	0,0	psi	0,0	psi	**0,00%**
	P_ω		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_γ	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	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%**

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_γ	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_γ	-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_γ	-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_γ	-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_γ	-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	

		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%**
		$\lvert\sigma_{elastic}\rvert$	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%**
		$\lvert\sigma_{elastic}\rvert$	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%**
		$\lvert\sigma_{elastic}\rvert$	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%**

		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%**
		$\lvert\sigma_{elastic}\rvert$	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		**Q_2**	-13986,0	N	-3144,2	lbf	-4259,3	psi	**26,18%**
		Q_3			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%**
		$\lvert\sigma_{elastic}\rvert$	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		**Q_2**	-32505,7	N	-7307,6	lbf	-7363,3	psi	**0,76%**
		Q_3			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%**
		$\lvert\sigma_{elastic}\rvert$	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		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									

	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%**
	$\sigma_{t,1}$	-27,8	Mpa	-4026,9	psi	-4024,0	psi	**0,07%**
	$F_{t,max}$			3,8		3,8		**0,16%**
	$\sigma_{t,2}$	52,3	Mpa	7590,0	psi	7570,0	psi	**0,26%**
2	$F_{t,min}$			-1,0		-1,0		**0,11%**
	$\sigma_{t,1}$	1,9	Mpa	269,6	psi	269,0	psi	**0,23%**
	$F_{t,max}$			3,7		3,7		**0,24%**
	$\sigma_{t,2}$	6,0	Mpa	864,9	psi	865,0	psi	**0,01%**
3	$F_{t,min}$			-1,1		-1,1		**0,03%**
	$\sigma_{t,1}$	-25,9	Mpa	-3757,3	psi	-3755,0	psi	**0,06%**
	$F_{t,max}$			3,8		3,8		**0,17%**
	$\sigma_{t,2}$	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%**
	$\sigma_{t,1}$	-27,7	Mpa	-4014,0	psi	-4028,8	psi	**0,37%**
	$F_{t,max}$			3,9		3,8		**1,17%**
	$\sigma_{t,2}$	53,0	Mpa	7689,3	psi	7580,9	psi	**1,43%**
2	$F_{t,min}$			-4,2		-5,5		**23,19%**
	$\sigma_{t,1}$	-1,1	Mpa	-153,7	psi	-322,2	psi	**52,29%**
	$F_{t,max}$			10,6		13,3		**20,23%**
	$\sigma_{t,2}$	12,3	Mpa	1783,5	psi	2137,0	psi	**16,54%**
3	$F_{t,min}$			-1,1		-1,1		**0,70%**
	$\sigma_{t,1}$	-25,8	Mpa	-3743,8	psi	-3760,0	psi	**0,43%**
	$F_{t,max}$			3,8		3,8		**1,15%**
	$\sigma_{t,2}$	59,0	Mpa	8558,7	psi	8445,5	psi	**1,34%**

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%**	
	$\lvert\sigma_{t,min}\rvert$	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%**	
	$\lvert\sigma_{t,min}\rvert$		Mpa		psi		psi		
	Fs								
	S_{tb}		Mpa		psi		psi		
3	$\sigma_{t,max}$	58,3	Mpa	8454,8	psi	8435,0	psi	**0,24%**	
	$\lvert\sigma_{t,min}\rvert$	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%**	
	$\lvert\sigma_{t,min}\rvert$	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%**	
	$\lvert\sigma_{t,min}\rvert$	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%**	
	$\lvert\sigma_{t,min}\rvert$	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%**	

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%**	

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	
Tube side pressure only (Ps=0) without differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio	-			*0.3*		*0.3*	
Allowance	c_1	*0*	in	*0*	in	*0*	in
Corros. all.	c_2	0	in	*0*	in	*0*	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
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

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		in²
Tube pitch (center distance)		p	*1.25*	in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in
Tube length between inner tubesheet faces		L	*161.9*	in
Unsupported tube span for buckling		l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	1	
Equivalent free buckling length k·l		l_t	***59***	in
Bellows inside diameter at its convolution height		D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	*1*	

Material properties for mean operating temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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 l1+l'1=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**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. UHX-9		Shell		Channel	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512301**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.235**	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(Am+Ab)·Ksp/Ssp,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_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	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: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1-N_t\cdot(0.5\cdot d_t TUBE/a_0)^2$	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 Kj/(Ks+Kj)	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	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 **6.53**	Z_w	**0.06434**	

Step 4					
Diameter ratio = A/D0				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					
γ(*)	**0** in	ω_S	**2.685** in²	ω_S*	**-2.654** in²
ω_C	**0** in²	ω_C*	**9.639** in²	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_ω	**0** psi

Step 6					
P_s'	**0** psi	P_t'	**860900** psi	P_γ	**0** psi
P_W	**231.4** psi	P_{rim}	**180.8** psi	P_e	**-399.4** psi

UHX-13.5.7 Step 7

Q_2 **-7049** lbf Q_3 **0.09763** F_m **0.09758**

Strength condition for the tubesheet bending stress, case 1

σ = **25520** psi $< 1.5 \cdot \sigma_B$ = 1.5· ***17952*** psi case 1-3

$< S_{PS}$ = **54515** psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi $\leq$ MIN[$0.8\sigma_B$; $0.533\ S_y$] = **14362** psi

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

F_{tmin} **-1.082** F_{tmax} **3.807**

x_{min} **0** x_{max} **3.971**

$\sigma_{T,1}$ **-4030** psi $\sigma_{T,2}$ **7570** psi

σ_{tmax} = **7570** psi $\leq \sigma_T$ = ***10430*** psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **20860** psi for calculation case 4-7

Tube weld force W_t = **1810** lbf $\leq W_{t,all}$ = 0 lbf

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

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

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

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.1875* in : (calculation case)

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

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

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

| **26.09** psi | < Min(**8493** psi , **16994** psi)

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

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

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

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 13.5.10 satisfied

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

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

σ_S = | **26.09** psi | + | **-42415** psi | ≤ **26929** psi

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

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

Minimum shell length with uniform thickness l_{Sm} **4.595** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is violated!

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

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

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:
σ_S = **42441** psi ≤ **54515** psi $=S_{PSs}$
with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:
σ_C = **0** psi ≤ ***0*** psi $=S_{PSc}$

Geometric conditions:
valid

Strength condition for linked modules (Connection activated: 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 c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

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

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °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

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

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

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

UHX-13.5.2 Step 2

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

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

UHX-13.5.3 Step 3

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

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

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

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

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

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

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	
Shell side pressure only (Pt=0) without differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio	-			*0.3*		*0.3*	
Allowance	c_1	*0*	in	*0*	in	*0*	in
Corros. all.	c_2	0	in	*0*	in	*0*	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
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

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		in²
Tube pitch (center distance)		p	*1.25*	in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in
Tube length between inner tubesheet faces		L	*161.9*	in
Unsupported tube span for buckling		l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	**1**	
Equivalent free buckling length k·l		l_t	***59***	in
Bellows inside diameter at its convolution height		D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	*1*	

Material properties for mean operating temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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 l1+l'1=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**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. UHX-9		Shell		Channel	
Effective seating width	b		in	0.2505	in
Gasket operating force	W	0	lbf	0	lbf
Total req. bolt root area	A_m	0	in²	8.801	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	0	in	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)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	0	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	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_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	0.2	
Effective tube hole diameter	d*	0.8915	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: Dc/2, else:Gc/2)	a_c	18.4	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	17.38	in
Ratio = ac/a0	ρ_C	1.074	
Ratio = as/a0	ρ_S	1.014	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	0.4471	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	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 $K_s/(N_t\cdot K_t)$	K_{st}	0.1326	
Stiffness ratio Kj/(Ks+Kj)	J	0.003504	

Step 3									
Effective modulus of el. tubesheet		UHX-11.3					E*	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/D0				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					
γ(*)	0 in	ω_S	2.685 in²	ω_S*	-2.654 in²
ω_C	0 in²	ω_C*	9.639 in²	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_ω	0 psi

Step 6					
P_s'	-46159 psi	P_t'	0 psi	P_γ	0 psi
P_W	0 psi	P_{rim}	18.67 psi	P_e	-21.42 psi

UHX-13.5.7 Step 7

Q_2 **-319.3** lbf Q_3 **0.07895** F_m **0.09025**

Strength condition for the tubesheet bending stress, case 2

σ = **1266** psi $< 1.5 \cdot \sigma_B$ = 1.5· ***17952*** psi case 1-3

$< S_{PS}$ = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi $\leq$ MIN[$0.8\sigma_B$; $0.533\ S_y$] = **14362** psi

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

F_{tmin} **-1.013** F_{tmax} **3.659**

x_{min} **0** x_{max} **3.971**

$\sigma_{T,1}$ **269.5** psi $\sigma_{T,2}$ **863.9** psi

σ_{tmax} = **863.9** psi $\leq \sigma_T$ = ***10430*** psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **20860** psi for calculation case 4-7

Tube weld force W_t = **206.6** lbf $\leq W_{t,all}$ = 0 lbf

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

r_t **0.3255** in F_t **181.2** C_t **1.421** F_s **164.2**

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

Strength acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.1875* in : (calculation case)

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

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

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

| **-763.7** psi | < Min(**8493** psi , **16994** psi)

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

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

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

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 13.5.10 satisfied

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

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

σ_S = | **-763.7** psi | + | **19223** psi | ≤ **26929** psi

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

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

Minimum shell length with uniform thickness l_{Sm} **4.595** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

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

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

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:
σ_S = **19987** psi ≤ *54515* psi $=S_{PSs}$
with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:
σ_C = **0** psi ≤ ***0*** psi $=S_{PSc}$

Geometric conditions:
valid

Strength condition for linked modules (Connection activated: No):
13.4(d) If: Tube sheet thickness= *3.062* in < *1* in
= Tube outside diameter, the tubesheet deformation must be considered.
UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

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

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °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

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

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

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

UHX-13.5.2 Step 2

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

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

UHX-13.5.3 Step 3

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

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

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

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

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

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

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

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		in²
Tube pitch (center distance)		p	*1.25*	in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in
Tube length between inner tubesheet faces		L	*161.9*	in
Unsupported tube span for buckling		l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	**1**	
Equivalent free buckling length k·l		l_t	***59***	in
Bellows inside diameter at its convolution height		D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	*1*	

Material properties for mean operating temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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 l1+l'1=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**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. UHX-9		Shell		Channel	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512301**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.235**	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(Am+Ab)·Ksp/Ssp,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_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	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: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	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 $K_s/(N_t\cdot K_t)$	K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.003504**	

Step 3			
Effective modulus of el. tubesheet UHX-11.3	E*	**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/D0				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					
γ(*)	**0** in	ω_S	**2.685** in²	ω_S*	**-2.654** in²
ω_C	**0** in²	ω_C*	**9.639** in²	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_ω	**0** psi

Step 6					
P_s'	**-46159** psi	P_t'	**860900** psi	P_γ	**0** psi
P_W	**231.4** psi	P_{rim}	**199.5** psi	P_e	**-420.8** psi

UHX-13.5.7 Step 7

Q_2 **-7369** lbf Q_3 **0.09668** F_m **0.09721**

Strength condition for the tubesheet bending stress, case 3

σ = **26783** psi $< 1.5 \cdot \sigma_B$ = 1.5· ***17952*** psi case 1-3

$< S_{PS}$ = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi $\leq$ MIN[$0.8\sigma_B$; $0.533\ S_y$] = **14362** psi

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

F_{tmin} **-1.078** F_{tmax} **3.799**

x_{min} **0** x_{max} **3.971**

$\sigma_{T,1}$ **-3760** psi $\sigma_{T,2}$ **8434** psi

σ_{tmax} = **8434** psi $\leq \sigma_T$ = ***10430*** psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **20860** psi for calculation case 4-7

Tube weld force W_t = **2017** lbf $\leq W_{t,all}$ = 0 lbf

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

r_t **0.3255** in F_t **181.2** C_t **1.35** F_s **164.2**

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

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.1875* in : (calculation case)

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

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

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

| **-737.6** psi | < Min(**8493** psi , **16994** psi)

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

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

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

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 13.5.10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **23929** psi $\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}

σ_S = | **-737.6** psi | + | **-23192** psi | ≤ **26929** psi

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

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

Minimum shell length with uniform thickness l_{Sm} **4.595** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

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

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

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

σ_S = **23929** psi ≤ *54515* psi $=S_{PSs}$

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

σ_C = **0** psi ≤ ***0*** psi $=S_{PSc}$

Geometric conditions:

valid

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

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

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

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

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

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °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

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

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

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

UHX-13.5.2 Step 2

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

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

UHX-13.5.3 Step 3

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

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

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

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

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

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

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 (Ps=Pt=0)				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio	-			*0.3*		*0.3*	
Allowance	c_1	*0*	in	*0*	in	*0*	in
Corros. all.	c_2	0	in	*0*	in	*0*	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
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

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		in²
Tube pitch (center distance)		p	*1.25*	in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	0	in
Tube length between inner tubesheet faces		L	*161.9*	in
Unsupported tube span for buckling		l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	**1**	
Equivalent free buckling length k·l		l_t	***59***	in
Bellows inside diameter at its convolution height		D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	*1*	

Material properties for mean operating temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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 l1+l'1=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**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. UHX-9		Shell		Channel	
Effective seating width	b		in	0.2505	in
Gasket operating force	W	0	lbf	0	lbf
Total req. bolt root area	A_m	0	in²	8.82	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	0	in	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)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	366091	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_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	0.2	
Effective tube hole diameter	d*	0.8915	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: Dc/2, else:Gc/2)	a_c	18.4	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	17.38	in
Ratio = ac/a0	ρ_C	1.074	
Ratio = as/a0	ρ_S	1.014	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	0.4471	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	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 $K_s/(N_t\cdot K_t)$	K_{st}	0.1326	
Stiffness ratio Kj/(Ks+Kj)	J	0.003504	

Step 3			
Effective modulus of el. tubesheet UHX-11.3	E*	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/D0				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					
γ(*)	-0.04727 in	ω_S	2.685 in²	ω_S*	-2.654 in²
ω_C	0 in²	ω_C*	9.639 in²	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_ω	0 psi

Step 6					
P_s'	0 psi	P_t'	0 psi	P_γ	-1252 psi
P_W	165.2 psi	P_{rim}	0 psi	P_e	-0.5045 psi

UHX-13.5.7 Step 7

Q_2 **-2825** lbf Q_3 **38.14** F_m **19.15**

Strength condition for the tubesheet bending stress, 4 case

σ = **6324** psi $< 1.5 \cdot \sigma_B$ = 1.5· 17952 psi case 1-3

$< S_{PS}$ = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi $\leq$ MIN[$0.8\sigma_B$; $0.533\ S_y$] = **14362** psi

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

F_{tmin}	**-143.8**	F_{tmax}	**305.1**
x_{min}	**0**	x_{max}	**4.02**
$\sigma_{T,1}$	**-431.1** psi	$\sigma_{T,2}$	**914.2** psi

σ_{tmax} = **914.2** psi $\leq \sigma_T$ = ***10430*** psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **20860** psi for calculation case 4-7

Tube weld force W_t = **218.6** lbf $\leq W_{t,all}$ = 0 lbf

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

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

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

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.1875* in : (calculation case)

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

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

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

| **-22.6** psi |	< Min(	**8493** psi	,	**16994** psi	)	
ASME external pressure chart	CS-2	A =	**0.001334**			

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

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

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

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

| psi |	< Min(	psi	,	psi	)	
ASME external pressure chart		A =				

Strength condition 13.5.10 satisfied

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

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

σ_S = | **-22.6** psi | + | **-7583** psi | ≤ **54515** psi

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

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

Minimum shell length with uniform thickness l_{Sm} **4.595** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

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

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

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

σ_S = **7606** psi ≤ *54515* psi $=S_{PSs}$

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

σ_C = **0** psi ≤ ***0*** psi $=S_{PSc}$

Geometric conditions:

valid

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

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

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

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

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

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °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

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

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

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

UHX-13.5.2 Step 2

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

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

UHX-13.5.3 Step 3

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

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

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

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

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

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

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	
Tube side pressure only (Ps=0) with differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation	**Tubesheet**		**Tubes**		**Shell**	
Temperature	*700*	°F	*700*	°F	*700*	°F
Thickness	3.062	in	*0.083*	in	*0.1875*	in
Outside diameter	*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio -			*0.3*		*0.3*	
Allowance c_1	*0*	in	*0*	in	*0*	in
Corros. all. c_2	0	in	*0*	in	*0*	in
Properties for the selected load case temperature						
Strength operat.	17952	psi	10430	psi	17952	psi
Safety operation	1		1		1	
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

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		in²
Tube pitch (center distance)		p	*1.25*	in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in
Tube length between inner tubesheet faces		L	*161.9*	in
Unsupported tube span for buckling		l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	**1**	
Equivalent free buckling length k·l		l_t	***59***	in
Bellows inside diameter at its convolution height		D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	*1*	

Material properties for mean operating temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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 l1+l'1=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**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. UHX-9		Shell		Channel	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512301**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.54**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	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(Am+Ab)·Ksp/Ssp,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_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	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: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	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 $K_s/(N_t\cdot K_t)$	K_{st}	**0.1326**	
Stiffness ratio Kj/(Ks+Kj)	J	**0.003504**	

Step 3			
Effective modulus of el. tubesheet UHX-11.3	E*	**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/D0				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					
γ(*)	**-0.04727** in	ω_S	**2.685** in²	ω_S*	**-2.654** in²
ω_C	**0** in²	ω_C*	**9.639** in²	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_ω	**0** psi

Step 6					
P_s'	**0** psi	P_t'	**860900** psi	P_γ	**-1252** psi
P_W	**231.2** psi	P_{rim}	**180.8** psi	P_e	**-400** psi

UHX-13.5.7 Step 7

Q_2 **-7046** lbf Q_3 **0.09739** F_m **0.09749**

Strength condition for the tubesheet bending stress, case 5

σ = **25532** psi $< 1.5 \cdot \sigma_B$ = 1.5· 17952 psi case 1-3

$< S_{PS}$ = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi $\leq$ MIN[0.8σ_B ; 0.533 S_y] = **14362** psi

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

F_{tmin} **-1.081** F_{tmax} **3.805**

x_{min} **0** x_{max} **4.02**

$\sigma_{T,1}$ **-4031** psi $\sigma_{T,2}$ **7579** psi

σ_{tmax} = **7579** psi $\leq \sigma_T$ = ***10430*** psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **20860** psi for calculation case 4-7

Tube weld force W_t = **1812** lbf $\leq W_{t,all}$ = 0 lbf

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

r_t **0.3255** in F_t **181.2** C_t **1.348** F_s **164.2**

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

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.1875* in : (calculation case)

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

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

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

| **0.05837** psi | < Min(**8493** psi , **16994** psi)

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

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

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

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 13.5.10 satisfied

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

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

σ_S = | **0.05837** psi | + | **-42439** psi | ≤ **54515** psi

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

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

Minimum shell length with uniform thickness l_{Sm} **4.595** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

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

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

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

σ_S = **42439** psi ≤ *54515* psi $=S_{PSs}$

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

σ_C = **0** psi ≤ ***0*** psi $=S_{PSc}$

Geometric conditions:

valid

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

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

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

UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

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

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °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

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

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

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

UHX-13.5.2 Step 2

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

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

UHX-13.5.3 Step 3

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

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

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

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

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

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

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	
Shell side pressure only (Pt=0) with differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

Operation	**Tubesheet**		**Tubes**		**Shell**	
Temperature	*700*	°F	*700*	°F	*700*	°F
Thickness	3.062	in	*0.083*	in	*0.1875*	in
Outside diameter	*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio -			*0.3*		*0.3*	
Allowance c_1	*0*	in	*0*	in	*0*	in
Corros. all. c_2	0	in	*0*	in	*0*	in
Properties for the selected load case temperature						
Strength operat.	17952	psi	10430	psi	17952	psi
Safety operation	1		1		1	
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

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		in²
Tube pitch (center distance)		p	*1.25*	in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in
Tube length between inner tubesheet faces		L	*161.9*	in
Unsupported tube span for buckling		l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	**1**	
Equivalent free buckling length k·l		l_t	***59***	in
Bellows inside diameter at its convolution height		D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	*1*	

Material properties for mean operating temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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 l1+l'1=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**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. UHX-9		Shell		Channel	
Effective seating width	b		in	0.2505	in
Gasket operating force	W	0	lbf	0	lbf
Total req. bolt root area	A_m	0	in²	8.801	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	0	in	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)		*Y*	(Y,N)
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp,App.2-5	W	366642	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_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	0.2	
Effective tube hole diameter	d*	0.8915	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: Dc/2, else:Gc/2)	a_c	18.4	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	17.38	in
Ratio = ac/a0	ρ_C	1.074	
Ratio = as/a0	ρ_S	1.014	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	0.4471	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	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 $K_s/(N_t\cdot K_t)$	K_{st}	0.1326	
Stiffness ratio Kj/(Ks+Kj)	J	0.003504	

Step 3							
Effective modulus of el. tubesheet	UHX-11.3				E*	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/D0				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					
γ(*) -0.04727 in		ω_S 2.685 in²		ω_S*	-2.654 in²
ω_C 0 in²		ω_C* 9.639 in²		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_ω	0 psi

Step 6					
P_s' -46159 psi		P_t' 0 psi		P_γ	-1252 psi
P_W 165.4 psi		P_{rim} 18.67 psi		P_e	-21.92 psi

UHX-13.5.7 Step 7

Q_2 **-3149** lbf Q_3 **0.9563** F_m **0.5009**

Strength condition for the tubesheet bending stress, 6 case

σ = **7190** psi $< 1.5 \cdot \sigma_B$ = 1.5· 17952 psi case 1-3

$< S_{PS}$ = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi $\leq$ MIN[$0.8\sigma_B$; $0.533\ S_y$] = **14362** psi

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

F_{tmin} **-4.254** F_{tmax} **10.61**

x_{min} **0** x_{max} **3.971**

$\sigma_{T,1}$ **-155.6** psi $\sigma_{T,2}$ **1779** psi

σ_{tmax} = **1779** psi $\leq \sigma_T$ = ***10430*** psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **20860** psi for calculation case 4-7

Tube weld force W_t = **425.5** lbf $\leq W_{t,all}$ = 0 lbf

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

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

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

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.1875* in : (calculation case)

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

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

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

| **-786.3** psi | < Min(**8493** psi , **16994** psi)

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

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

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

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 13.5.10 satisfied

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

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

σ_S = | **-786.3** psi | + | **11629** psi | ≤ **54515** psi

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

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

Minimum shell length with uniform thickness l_{Sm} **4.595** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

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

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

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:
σ_S = **12415** psi ≤ *54515* psi $=S_{PSs}$
with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:
σ_C = **0** psi ≤ ***0*** psi $=S_{PSc}$

Geometric conditions:
valid

Strength condition for linked modules (Connection activated: No):
13.4(d) If: Tube sheet thickness= 3.062 in < *1* in
= Tube outside diameter, the tubesheet deformation must be considered.
UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

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

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °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

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

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

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

UHX-13.5.2 Step 2

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

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

UHX-13.5.3 Step 3

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

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

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

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

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

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

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

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		in²
Tube pitch (center distance)		p	*1.25*	in
Total untubed area	UL1·LL1+UL2·LL2.. UHX-11.2	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in
Tube length between inner tubesheet faces		L	*161.9*	in
Unsupported tube span for buckling		l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)		k	**1**	
Equivalent free buckling length k·l		l_t	***59***	in
Bellows inside diameter at its convolution height		D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)		K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress		E_{sw}	*1*	

Material properties for mean operating temperature

Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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 l1+l'1=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**	in²
Bolt material	*G41400-SA-193-B7-Class:-Size:<=64*		
Strength for operation	K_s	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. UHX-9		Shell		Channel	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512301**	lbf
Total req. bolt root area	A_m	**0**	in²	**20.54**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	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(Am+Ab)·Ksp/Ssp,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_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	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: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1-N_t\cdot(0.5\cdot d_t TUBE/a_0)^2$	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 Kj/(Ks+Kj)	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/D0				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					
γ(*)	**-0.04727** in	ω_S	**2.685** in²	ω_S*	**-2.654** in²
ω_C	**0** in²	ω_C*	**9.639** in²	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_ω	**0** psi

Step 6					
P_s'	**-46159** psi	P_t'	**860900** psi	P_γ	**-1252** psi
P_W	**231.2** psi	P_{rim}	**199.5** psi	P_e	**-421.4** psi

UHX-13.5.7 Step 7

Q_2 **-7365** lbf Q_3 **0.09646** F_m **0.09712**

Strength condition for the tubesheet bending stress, 7 case

σ = **26796** psi $< 1.5 \cdot \sigma_B$ = 1.5· 17952 psi case 1-3

$< S_{PS}$ = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi $\leq$ MIN[$0.8\sigma_B$; $0.533\ S_y$] = **14362** psi

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

F_{tmin} **-1.078** F_{tmax} **3.797**

x_{min} **0** x_{max} **4.02**

$\sigma_{T,1}$ **-3762** psi $\sigma_{T,2}$ **8442** psi

σ_{tmax} = **8442** psi $\leq \sigma_T$ = ***10430*** psi for calculation case 1-3

$\leq 2 \cdot \sigma_T$ = **20860** psi for calculation case 4-7

Tube weld force W_t = **2019** lbf $\leq W_{t,all}$ = 0 lbf

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

r_t **0.3255** in F_t **181.2** C_t **1.351** F_s **164.2**

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

Buckling stability acc. UHX-13.5.9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.1875* in : (calculation case)

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

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

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

| **-763.6** psi | < Min(**8493** psi , **16994** psi)

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

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

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

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 13.5.10 satisfied

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

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

σ_S = | **-763.6** psi | + | **-23216** psi | ≤ **54515** psi

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

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

Minimum shell length with uniform thickness l_{Sm} **4.595** in

Minimum channel thickness with uniform thickness l_{Cm} in

Strength condition UHX-13.5.11 is satisfied

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

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

Acc. to option 3 the modulus of elasticity of the shell E_S is replaced by $E_S \cdot f_{actS}$, under the conditions:
σ_S = **23980** psi ≤ *54515* psi $=S_{PSs}$
with the allowable primary and secondary stress SPSS, if the allowable stress σallS is outside of the creep range! Analogously for the channel:
σ_C = **0** psi ≤ ***0*** psi $=S_{PSc}$

Geometric conditions:
valid

Strength condition for linked modules (Connection activated: No):
13.4(d) If: Tube sheet thickness= *3.062* in < *1* in
= Tube outside diameter, the tubesheet deformation must be considered.
UHX-11.4(b): The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to UHX-13.4(e)(2) the shell must eventually be designed for column buckling (in the case of compression).

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

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °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

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

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

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

UHX-13.5.2 Step 2

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

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

UHX-13.5.3 Step 3

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

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

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

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

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

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