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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 11.0.8.24
Developed by Lauterbach Verfahrenstechnik GmbH
Certified per DIn EN ISO 9001:2008 Certificate Number 01 100 044763

Example 4.18.7 - Fixed Tubesheet Exchanger , Configuration a, 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***	2,3E+01	mm	9,10E-01	in	9,1E-01	in	**0,00%**
Effective pitch	**p***	3,2E+01	mm	1,25E+00	in	1,3E+00	in	**0,00%**
Eff. ligament efficiency	**μ***			2,72E-01		2,7E-01		**0,00%**
Parameter	x_s			4,39E-01		4,4E-01		**0,05%**
Parameter	x_t			5,44E-01		5,4E-01		**0,03%**

Step 2

		LV Soft				ASME		Diff [%]
Coefficients for shell	δ_s	9,3E-02	mm^3/N	2,53E-05	in^3/lbf	2,5E-05	in^3/lbf	**0,78%**
	β_s	1,5E-02	1/mm	3,72E-01	1/in	3,7E-01	1/in	**0,17%**
	k_s	1,4E+06	N	3,20E+05	lbf	3,2E+05	lbf	**0,49%**
	λ_s	2,8E+05	Mpa	4,10E+07	psi	4,1E+07	psi	**0,00%**
	δc	1,3E-01	mm^3/N	3,57E-05	in^3/lbf	3,6E-05	in^3/lbf	**0,50%**
	βc	1,8E-02	1/mm	4,55E-01	1/in	4,6E-01	1/in	**0,01%**
	kc	5,5E+05	N	1,24E+05	lbf	1,2E+05	lbf	**0,03%**
	λc	1,2E+05	Mpa	1,79E+07	psi	1,8E+07	psi	**0,01%**
Shell axial rigidity	K_s	1,5E+06	N/mm	8,38E+06	lbf/in	8,4E+06	lbf/in	**0,00%**
Tube axial rigidity	K_t	2,9E+03	N/mm	1,67E+04	lbf/in	1,7E+04	lbf/in	**0,01%**
Stiffness ratio	K_{st}			5,26E-01		5,3E-01		**0,02%**
Stiffness ratio	**J**			1,00E+00		1,0E+00		**0,00%**

Step 3

		LV Soft	ASME	Diff [%]
Ratio of elasticity tubesheet	**E*/E**	2,72E-01	2,7E-01	**0,00%**
effective Poisson's ratio tubesheet	**ν***	3,44E-01	3,4E-01	**0,00%**

Parameter for table UHX-13.2	X_a	6,59E+00	6,6E+00	**0,02%**
	Z_d	5,24E-03	5,2E-03	**0,03%**
	Z_v	2,34E-02	2,3E-02	**0,00%**
	Z_m	2,20E-01	2,2E-01	**0,00%**
	Z_a	1,71E+02	1,7E+02	**0,00%**
	Z_w	2,34E-02	2,3E-02	**0,00%**

Step 4

		LV Soft	ASME	Diff [%]
Diameter ratio	**K**	1,05E+00	1,0E+00	**0,00%**
Corfficient	**F**	5,48E+00	5,5E+00	**0,00%**
Parameter	**Φ**	7,37E+00	7,4E+00	**0,01%**
	Q_1	-5,88E-02	-5,9E-02	**0,05%**
	Q_{z1}	3,64E+00	3,6E+00	**0,00%**
	Q_{z2}	9,82E+00	9,8E+00	**0,01%**
	U	1,96E+01	2,0E+01	**0,00%**

Step 5

		LV Soft				ASME		Diff [%]
	γ(*)							
	ω_s	3,1E+03	mm^2	4,75E+00	in^2	4,7E+00	in^2	**0,25%**
	ω_s*	-3,0E+03	mm^2	-4,68E+00	in^2	-4,7E+00	in^2	**0,27%**
	ω_c	2,2E+03	mm^2	3,46E+00	in^2	3,5E+00	in^2	**0,00%**
	ω_c*	-1,8E+03	mm^2	-2,73E+00	in^2	-2,7E+00	in^2	**0,50%**
	γ_b			1,00E-06		1,0E-06		**0,00%**

Summary table for Step 5 -Design Condition								
Loading Case								
1	**P_s**		Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	Pt		Mpa	2,00E+02	psi	2,0E+02	psi	**0,00%**
	γ	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**
	W	0,0E+00	N	0,00E+00	lbf	0,0E+00	lbf	**0,00%**
2	**P_s**		Mpa	3,25E+02	psi	3,3E+02	psi	**0,00%**
	Pt		Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	γ	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**

	W	0,0E+00	N	0,00E+00	lbf	0,0E+00	lbf	**0,00%**
3	P_s		Mpa	3,25E+02	psi	3,3E+02	psi	**0,00%**
	Pt		Mpa	2,00E+02	psi	2,0E+02	psi	**0,00%**
	γ	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**
	W	0,0E+00	N	0,00E+00	lbf	0,0E+00	lbf	**0,00%**

Summary table for Step 5 -Operation Condition								
Loading Case								
1	P_s		Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	Pt		Mpa	2,00E+02	psi	2,0E+02	psi	**0,00%**
	γ	-2,0E+00	mm	-8,06E-02	in	-8,1E-02	in	**0,30%**
	W	0,0E+00	N	0,00E+00	lbf	0,0E+00	lbf	**0,00%**
2	P_s		Mpa	3,25E+02	psi	3,3E+02	psi	**0,00%**
	Pt		Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	γ	-2,0E+00	mm	-8,06E-02	in	-8,1E-02	in	**0,30%**
	W	0,0E+00	N	0,00E+00	lbf	0,0E+00	lbf	**0,00%**
3	P_s		Mpa	3,25E+02	psi	3,3E+02	psi	**0,00%**
	Pt		Mpa	2,00E+02	psi	2,0E+02	psi	**0,00%**
	γ	-2,0E+00	mm	-8,06E-02	in	-8,1E-02	in	**0,30%**
	W	0,0E+00	N	0,00E+00	lbf	0,0E+00	lbf	**0,00%**
4	P_s		Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	Pt		Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	γ	-2,1E+00	mm	-8,09E-02	in	-8,1E-02	in	**0,09%**
	W	0,0E+00	N	0,00E+00	lbf	0,0E+00	lbf	**0,00%**

Summary table for Step 6 -Design Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	P_s'	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_t'	3,8E+00	Mpa	5,45E+02	psi	5,5E+02	psi	**0,01%**
	P_γ		Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_ω		Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_{rim}	-1,7E-01	Mpa	-2,52E+01	psi	-2,5E+01	psi	**0,44%**
	P_e	-6,9E-01	Mpa	-9,98E+01	psi	-1,0E+02	psi	**0,03%**
2	P_s'	4,3E+00	Mpa	6,30E+02	psi	6,3E+02	psi	**0,01%**

	P_t'	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_γ	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_{rim}	4,8E-01	Mpa	7,02E+01	psi	7,0E+01	psi	**0,21%**
	P_e	8,4E-01	Mpa	1,22E+02	psi	1,2E+02	psi	**0,03%**
3	P_s'	4,3E+00	Mpa	6,30E+02	psi	6,3E+02	psi	**0,01%**
	P_t'	3,8E+00	Mpa	5,45E+02	psi	5,5E+02	psi	**0,00%**
	P_γ	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_{rim}	3,1E-01	Mpa	4,51E+01	psi	4,5E+01	psi	**0,29%**
	P_e	1,6E-01	Mpa	2,27E+01	psi	2,3E+01	psi	**0,19%**

Summary table for Step 6 -Operation Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	P_s'	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_t'	3,8E+00	Mpa	5,45E+02	psi	5,5E+02	psi	**0,00%**
	P_γ	-6,6E+00	Mpa	-9,60E+02	psi	-9,6E+02	psi	**0,35%**
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_{rim}	-1,7E-01	Mpa	-2,51E+01	psi	-2,5E+01	psi	**0,08%**
	P_e	-1,8E+00	Mpa	-2,68E+02	psi	-2,7E+02	psi	**0,20%**
2	P_s'	4,3E+00	Mpa	6,30E+02	psi	6,3E+02	psi	**0,01%**
	P_t'	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_γ	-6,6E+00	Mpa	-9,60E+02	psi	-9,6E+02	psi	**0,35%**
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_{rim}	4,8E-01	Mpa	7,02E+01	psi	7,0E+01	psi	**0,16%**
	P_e	-3,1E-01	Mpa	-4,53E+01	psi	-4,6E+01	psi	**1,31%**
3	P_s'	4,3E+00	Mpa	6,30E+02	psi	6,3E+02	psi	**0,01%**
	P_t'	3,8E+00	Mpa	5,45E+02	psi	5,5E+02	psi	**0,00%**
	P_γ	-6,6E+00	Mpa	-9,60E+02	psi	-	psi	**0,35%**

						9,6E+02		
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_{rim}	3,1E-01	Mpa	4,51E+01	psi	4,5E+01	psi	**0,29%**
	P_e	-1,0E+00	Mpa	-1,45E+02	psi	-1,5E+02	psi	**0,41%**
4	P_s'	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_t'	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_γ	-6,6E+00	Mpa	-9,63E+02	psi	-9,6E+02	psi	**0,04%**
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_{rim}	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_e	-1,2E+00	Mpa	-1,68E+02	psi	-1,7E+02	psi	**0,09%**

Summary table for Step 7 -Design Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	Q_2	9,3E+02	N	2,08E+02	lbf	2,1E+02	psi	**0,54%**
	Q_3			-6,86E-02		-6,9E-02	psi	**0,07%**
	F_m			3,43E-02		3,4E-02	psi	**0,09%**
	hg'			0,00E+00	in	0,0E+00	psi	**0,00%**
	h							
	h-hg'			1,50E+00	in	1,5E+00	psi	**0,00%**
	$\lvert\sigma_{elastic}\rvert$	9,9E+01	Mpa	1,43E+04	psi	1,4E+04	psi	**0,12%**
	1,5S	1,1E+02	Mpa	2,37E+04	psi	2,4E+04	psi	**0,00%**
2	Q_2	-2,6E+03	N	-5,80E+02	lbf	-5,8E+02	psi	**0,28%**
	Q_3			-8,11E-02		-8,1E-02	psi	**0,06%**
	F_m			4,05E-02		4,1E-02	psi	**0,07%**
	hg'			0,00E+00	in	0,0E+00	psi	**0,00%**
	h							
	h-hg'			1,50E+00	in	1,5E+00	psi	**0,00%**
	$\lvert\sigma_{elastic}\rvert$	1,4E+02	Mpa	2,07E+04	psi	2,1E+04	psi	**0,13%**
	1,5S	1,1E+02	Mpa	2,37E+04	psi	2,4E+04	psi	**0,00%**
3	Q_2	-1,7E+03	N	-3,72E+02	lbf	-	psi	**0,40%**

						3,7E+02		
	Q_3			-1,36E-01		-1,4E-01	psi	**0,15%**
	F_m			6,80E-02		6,8E-02	psi	**0,12%**
	hg'			0,00E+00	in	0,0E+00	psi	**0,00%**
	h							
	h-hg'			1,50E+00	in	1,5E+00	psi	**0,00%**
	$\lvert\sigma_{elastic}\rvert$	4,4E+01	Mpa	6,44E+03	psi	6,4E+03	psi	**0,36%**
	1,5S	1,1E+02	Mpa	2,37E+04	psi	2,4E+04	psi	**0,00%**

Summary table for Step 7 -Operation Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
	Q_2	9,2E+02	N	2,07E+02	lbf	2,1E+02	psi	**0,07%**
	Q_3			-6,25E-02		-6,2E-02		**0,06%**
	F_m			3,12E-02		3,1E-02		**0,06%**
1	**hg'**			0,00E+00	in	0,0E+00	in	**0,00%**
	h							
	h-hg'			1,50E+00	in	1,5E+00	in	**0,00%**
	$\lvert\sigma_{elastic}\rvert$	2,4E+02	Mpa	3,49E+04	psi	3,5E+04	psi	**0,07%**
	S_{ps}		Mpa	4,74E+04	psi	4,7E+04	psi	**0,00%**
	Q_2	-2,6E+03	N	-5,80E+02	lbf	-5,8E+02	psi	**0,28%**
	Q_3							**0,00%**
	F_m			3,73E-02		3,7E-02		**0,78%**
2	**hg'**			0,00E+00	in	0,0E+00	in	**0,00%**
	h							
	h-hg'			1,50E+00	in	1,5E+00	in	**0,00%**
	$\lvert\sigma_{elastic}\rvert$	5,0E+01	Mpa	7,24E+03	psi	7,1E+03	psi	**1,96%**
	S_{ps}			4,74E+04	psi	4,7E+04	psi	**0,00%**
	Q_2	-1,7E+03	N	-3,72E+02	lbf	-3,7E+02	psi	**0,40%**
	Q_3			-4,68E-02		-4,7E-02		**0,11%**
	F_m			2,33E-02		2,3E-02		**0,56%**
3	**hg'**			0,00E+00	in	0,0E+00	in	**0,00%**
	h							
	h-hg'			1,50E+00	in	1,5E+00	in	**0,00%**
	$\lvert\sigma_{elastic}\rvert$	9,8E+01	Mpa	1,42E+04	psi	1,4E+04	psi	**0,50%**

	S_{ps}		Mpa	4,74E+04	psi	4,7E+04	psi	**0,00%**
4	Q_2	0,0E+00	N	0,00E+00	lbf	0,0E+00	psi	**0,00%**
	Q_3			-5,88E-02		-5,9E-02		**0,05%**
	F_m			2,94E-02		2,9E-02		**0,07%**
	hg'			0,00E+00	in	0,0E+00	in	**0,00%**
	h							
	h-hg'			1,50E+00	in	1,5E+00	in	**0,00%**
	$\lvert\sigma_{elastic}\rvert$	1,4E+02	Mpa	2,07E+04	psi	2,1E+04	psi	**0,16%**
	S_{ps}		Mpa	4,74E+04	psi	4,7E+04	psi	**0,00%**

Summary table for Step 8 -Design Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	**0,8S**		Mpa	0,00E+00	psi		psi	**0,00%**
2	**0,8S**		Mpa	0,00E+00	psi		psi	**0,00%**
3	**0,8S**		Mpa	0,00E+00	psi		psi psi	**0,00%**

Summary table for Step 8 -Operation Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	**0,8S**		Mpa	0,00E+00	psi		psi	**0,00%**
2	**0,8S**		Mpa	0,00E+00	psi		psi	**0,00%**
3	**0,8S**		Mpa	0,00E+00	psi		psi	**0,00%**
4	**0,8S**		Mpa	0,00E+00	psi		psi	**0,00%**

Summary table for Step 9 -Design Condition			
	LV Soft	ASME	Diff [%]

Loading Case								
1	$F_{t,min}$			-2,82E-01		-2,8E-01		**0,04%**
	$\sigma_{t,1}$	-9,0E+00	Mpa	-1,31E+03	psi	-1,3E+03	psi	**0,06%**
	$F_{t,max}$			3,43E+00		3,4E+00		**0,03%**
	$\sigma_{t,2}$	1,5E+01	Mpa	2,23E+03	psi	2,2E+03	psi	**0,02%**
2	$F_{t,min}$			-2,57E-01		-2,6E-01		**0,04%**
	$\sigma_{t,1}$	1,1E+01	Mpa	1,67E+03	psi	1,7E+03	psi	**0,07%**
	$F_{t,max}$			3,15E+00		3,2E+00		**0,03%**
	$\sigma_{t,2}$	-1,6E+01	Mpa	-2,33E+03	psi	-2,3E+03	psi	**0,03%**
3	$F_{t,min}$			-2,19E-01		-2,2E-01		**0,00%**
	$\sigma_{t,1}$	2,6E+00	Mpa	3,72E+02	psi	3,7E+02	psi	**0,19%**
	$F_{t,max}$			2,12E+00		2,1E+00		**0,09%**
	$\sigma_{t,2}$	-9,3E-01	Mpa	-1,34E+02	psi	-1,3E+02	psi	**0,11%**

Summary table for Step 9 -Operation Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	$F_{t,min}$			-2,97E-01		-3,0E-01		**0,00%**
	$\sigma_{t,1}$	-1,2E+01	Mpa	-1,80E+03	psi	-1,8E+03	psi	**0,00%**
	$F_{t,max}$			3,56E+00		3,6E+00		**0,00%**
	$\sigma_{t,2}$	5,6E+01	Mpa	8,07E+03	psi	8,1E+03	psi	**0,19%**
2	$F_{t,min}$			-5,19E-01		-5,1E-01		**0,78%**
	$\sigma_{t,1}$	7,9E+00	Mpa	1,14E+03	psi	1,1E+03	psi	**0,23%**
	$F_{t,max}$			4,96E+00		4,9E+00		**0,40%**
	$\sigma_{t,2}$	2,4E+01	Mpa	3,52E+03	psi	3,5E+03	psi	**0,50%**
3	$F_{t,min}$			-3,40E-01		-3,4E-01		**0,06%**
	$\sigma_{t,1}$	-1,0E+00	Mpa	-1,47E+02	psi	-1,5E+02	psi	**1,28%**
	$F_{t,max}$			3,91E+00		3,9E+00		**0,03%**
	$\sigma_{t,2}$	4,0E+01	Mpa	5,75E+03	psi	5,8E+03	psi	**0,29%**
4	$F_{t,min}$			-3,06E-01		-3,1E-01		**0,03%**

	$\sigma_{t,1}$	-3,4E+00	Mpa	-4,93E+02	psi	-4,9E+02	psi	**0,15%**
	$F_{t,max}$			3,64E+00		3,6E+00		**0,00%**
	$\sigma_{t,2}$	4,0E+01	Mpa	5,87E+03	psi	5,9E+03	psi	**0,11%**

Summary table for Step 9 -Design Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	$\sigma_{t,max}$	1,5E+01	Mpa	2,23E+03	psi	2,2E+03	psi	**0,02%**
	$\lvert\sigma_{t,min}\rvert$	-9,0E+00	Mpa	-1,31E+03	psi	-1,3E+03	psi	**0,06%**
	Fs			1,54E+00		1,5E+00		**0,00%**
	S_{tb}	4,9E+01	Mpa	7,14E+03	psi	7,1E+03	psi	**0,09%**
2	$\sigma_{t,max}$	1,6E+01	Mpa	2,33E+03	psi	2,3E+03	psi	**0,03%**
	$\lvert\sigma_{t,min}\rvert$	-1,6E+01	Mpa	-2,33E+03	psi	-2,3E+03	psi	**0,03%**
	Fs			1,67E+00		1,7E+00		**0,00%**
	S_{tb}	4,5E+01	Mpa	6,56E+03	psi	6,6E+03	psi	**0,08%**
3	$\sigma_{t,max}$	2,6E+00	Mpa	3,72E+02	psi	3,7E+02	psi	**0,19%**
	$\lvert\sigma_{t,min}\rvert$	-9,3E-01	Mpa	-1,34E+02	psi	-1,3E+02	psi	**0,11%**
	Fs			2,00E+00		2,0E+00		**0,00%**
	S_{tb}	3,8E+01	Mpa	5,49E+03	psi	5,5E+03	psi	**0,06%**

Summary table for Step 9 -Operation Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	$\sigma_{t,max}$	5,6E+01	Mpa	8,07E+03	psi	8,1E+03	psi	**0,19%**
	$\lvert\sigma_{t,min}\rvert$	-1,2E+01	Mpa	-1,80E+03	psi	-1,8E+03	psi	**0,00%**

	Fs			1,47E+00		1,5E+00		**0,07%**
	S_{tb}	5,2E+01	Mpa	7,47E+03	psi	7,5E+03	psi	**0,08%**
2	**$\sigma_{t,max}$**	2,4E+01	Mpa	3,52E+03	psi	3,5E+03	psi	**0,50%**
	$\lvert\sigma_{t,min}\rvert$		Mpa	0,00E+00	psi		psi	
	Fs							
	S_{tb}		Mpa	0,00E+00	psi		psi	
3	**$\sigma_{t,max}$**	4,0E+01	Mpa	5,75E+03	psi	5,8E+03	psi	**0,29%**
	$\lvert\sigma_{t,min}\rvert$	-1,0E+00	Mpa	-1,47E+02	psi	-1,5E+02	psi	**1,28%**
	Fs			1,30E+00		1,3E+00		**0,08%**
	S_{tb}	5,8E+01	Mpa	8,47E+03	psi	8,5E+03	psi	**0,01%**
4	**$\sigma_{t,max}$**	4,0E+01	Mpa	5,87E+03	psi	5,9E+03	psi	**0,11%**
	$\lvert\sigma_{t,min}\rvert$	-3,4E+00	Mpa	-4,93E+02	psi	-4,9E+02	psi	**0,15%**
	Fs			1,43E+00		1,4E+00		**0,07%**
	S_{tb}	5,3E+01	Mpa	7,68E+03	psi	7,7E+03	psi	**0,07%**

Summary table for Step 10 und 11 -Design Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	**$\sigma_{s,m}$**	1,2E+01	Mpa	1,78E+03	psi	1,8E+03	psi	**0,02%**
	$\sigma_{s,b}$	-8,5E+01	Mpa	-1,23E+04	psi	-1,2E+04	psi	**0,09%**
	σ_s	9,7E+01	Mpa	1,41E+04	psi	1,4E+04	psi	**0,07%**
	1.5S_s	1,6E+02	Mpa	2,37E+04	psi	2,4E+04	psi	**0,00%**
2	**$\sigma_{s,m}$**	1,6E+01	Mpa	2,39E+03	psi	2,4E+03	psi	**0,02%**
	$\sigma_{s,b}$	2,0E+02	Mpa	2,86E+04	psi	2,9E+04	psi	**0,12%**
	σ_s	2,1E+02	Mpa	3,10E+04	psi	3,1E+04	psi	**0,10%**
	1.5S_s	1,6E+02	Mpa	2,37E+04	psi	2,4E+04	psi	**0,00%**
3	**$\sigma_{s,m}$**	2,9E+01	Mpa	4,17E+03	psi	4,2E+03	psi	**0,02%**
	$\sigma_{s,b}$	1,1E+02	Mpa	1,63E+04	psi	1,6E+04	psi	**0,19%**
	σ_s	1,4E+02	Mpa	2,04E+04	psi	2,0E+04	psi	**0,14%**
	1.5S_s	1,6E+02	Mpa	2,37E+04	psi	2,4E+04	psi	**0,00%**

Summary table for Step 10 und 11 -Operation Condition									
		LV Soft				ASME		Diff [%]	
Loading Case									
1	$\sigma_{s,m}$	-8,3E+00	Mpa	-1,20E+03	psi	-1,2E+03	psi	**0,75%**	
	$\sigma_{s,b}$	-2,6E+02	Mpa	-3,84E+04	psi	-3,9E+04	psi	**0,25%**	
	σ_s	2,7E+02	Mpa	3,96E+04	psi	4,0E+04	psi	**0,26%**	
	$S_{pS,s}$	3,3E+02	Mpa	4,74E+04	psi	4,7E+04	psi	**0,00%**	
2	$\sigma_{s,m}$	-4,1E+00	Mpa	-5,95E+02	psi	-6,0E+02	psi	**1,50%**	
	$\sigma_{s,b}$	1,7E+01	Mpa	2,48E+03	psi	2,4E+03	psi	**5,04%**	
	σ_s	2,1E+01	Mpa	3,07E+03	psi	3,0E+03	psi	**3,72%**	
	$S_{pS,s}$	3,3E+02	Mpa	4,74E+04	psi	4,7E+04	psi	**0,00%**	
3	$\sigma_{s,m}$	8,2E+00	Mpa	1,19E+03	psi	1,2E+03	psi	**0,79%**	
	$\sigma_{s,b}$	-6,8E+01	Mpa	-9,84E+03	psi	-1,0E+04	psi	**1,23%**	
	σ_s	7,6E+01	Mpa	1,10E+04	psi	1,1E+04	psi	**1,04%**	
	$S_{pS,s}$	3,3E+02	Mpa	4,74E+04	psi	4,7E+04	psi	**0,00%**	
4	$\sigma_{s,m}$	-2,1E+01	Mpa	-2,99E+03	psi	-3,0E+03	psi	**0,11%**	
	$\sigma_{s,b}$	-1,8E+02	Mpa	-2,62E+04	psi	-2,6E+04	psi	**0,04%**	
	σ_s	2,0E+02	Mpa	2,92E+04	psi	2,9E+04	psi	**0,05%**	
	$S_{pS,s}$	3,3E+02	Mpa	4,74E+04	psi	4,7E+04	psi	**0,00%**	

2 A188 - Fixed Tubesheets - ASME BPVC VIII-2, 2025

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

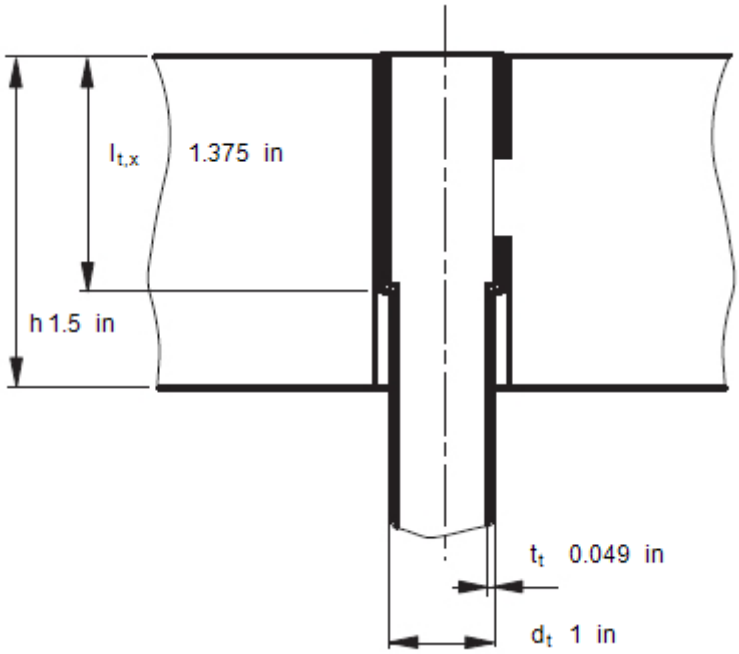
Configuration of the tubesheet (a, b, c, d)		Type	*a*
Tubesheet integral with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)			*1*
Internal operating pressure shell side		P_s	*325* psi
Internal operating pressure tube side		P_t	*200* psi
Internal test pressure shell side		P_{sp}	psi
Internal test pressure tube side		P_{tp}	psi
Load case	(1=operation, 2+3=test at 20°C, 4=other)		*1*
load case: operation			
Calculation case per 4.18.8.4:	(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	*S30403-SA-240-304L*		
Tube material	*S30403-SA-249-TP304L*		
Shell material (Type abc)	*S30403-SA-240-304L*		
Channel material (Type a)	*K02700-SA-516-70*		

Operation	**Tubesheet**	**Tubes**	**Shell**	**Channel**
Temperature	*400* °F	*300* °F	*400* °F	*300* °F
Thickness	*1.5* in	*0.049* in	*0.5625* in	0.375 in
Outside diameter	*43.13* in	*1* in	*43.13* in	*42.88* in
Poiss.ratio	-	*0.31*	*0.31*	*0.3*
Allow. c1	0 mm	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in	0 in
Properties for the selected load case temperature				
Strength op	15800 psi	16700 psi	15800 psi	22400 psi
Safety op.	1	1	1	1
Modulus of elasticity	*2.64e+7* psi	*2.7e+7* psi	*2.64e+7* psi	*2.83e+7* psi
Therm.exp.	*9.462* 1E-6/°F	*9.217* 1E-6/°F	*9.462* 1E-6/°F	*6.885* 1E-6/°F
Yield str.	*17446* psi	*19184* psi	*17446* psi	*33668* psi
Limit temperature	1000 °F	1000 °F	1000 °F	1000 °F
All.stress	***15800*** psi	***16700*** psi	***15800*** psi	***22400*** psi
Pr.+sec.st	***47400*** psi		***47400*** psi	***67336*** psi
Properties for testing at 20°C				
Strength	22191 psi	22191 psi	22191 psi	33939 psi
Safety	1	1	1	1
Yield str.	24656 psi	24656 psi	24656 psi	37710 psi
Tensile str.	70343 psi	70343 psi	70343 psi	70343 psi

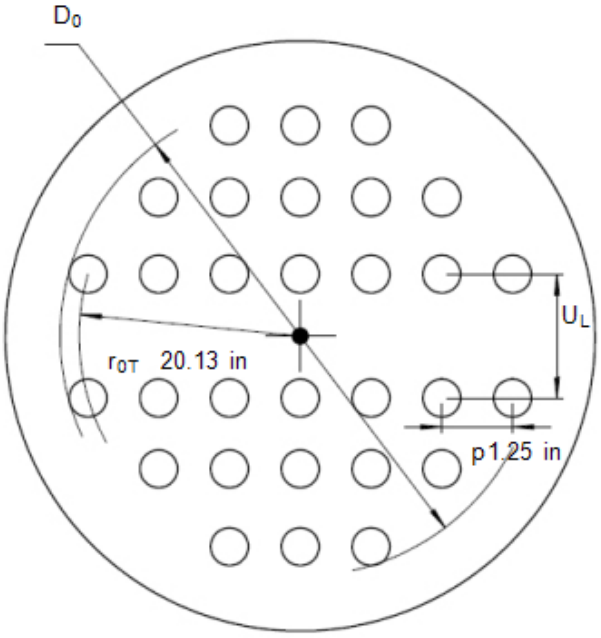
Additional specifications for the geometry and loading

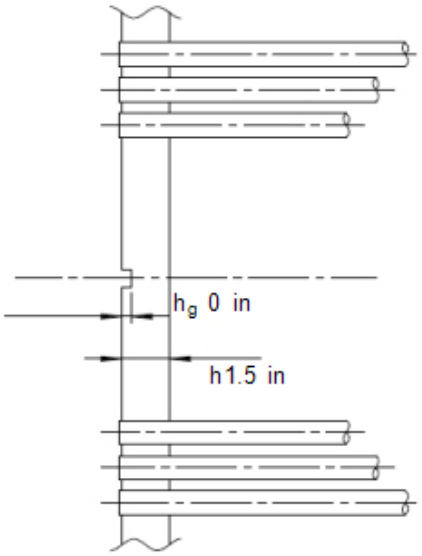
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	*1.375*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.9167**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*20.13*	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by C_p	Fig. 4.18.14	A_p		mm²
Tube pitch (center distance)		p	*1.25*	in





Total untubed area	UL1·LL1+UL2·LL2.. Fig. 4.18.3	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*237*	in
Unsupported tube span for buckling	l	*48*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	1	
Equivalent free buckling length k·l	l_t	***48***	in
Bellows inside diameter at its convolution height	D_j	*43.13*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*0.85*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.788*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.656*	1E-6/°F

4.18.8.7: 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'	*8.5*	1E-6/°F
Channel at T'_c	α'_c	*6.389*	1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*8.5*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		in

Maximum bolt force for all calculation cases	W_{max}	*0*	N

Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	***0.375***	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.13**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15765	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9104**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2717**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.439**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5436**	
Type abc: Coefficients for shell pressure	δ_S	**0.0927**	mm^3/N
β_S **0.3709** 1/in k_S **321305** lbf	λ_S	4.105e+7	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **0.4553** 1/in k_C **124455** lbf	λ_C	**1.786e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	8379598	lbf/in
Tube axial rigidity	K_t	16678	lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st}	0.5261	
Stiffness ratio Kj/(Ks+Kj)	J	1	

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2				E^*	7188365	psi
Ratio of elasticity tubesheet					E^*/E	0.2723	
effective Poisson's ratio tubesheet					v^*	0.3439	
Parameter for table 4.18.3					X_a	6.587	
Z_d 0.005244	Z_v 0.02338	Z_m 0.2202	Z_a 170.8		Z_w	0.02338	

Step 4

Diameter ratio = A/D0				K	1.045
F	5.484	Φ	7.37	Q_1	-0.0588
Q_{z1}	3.641	Q_{z2}	9.821	U	19.64

Step 5, coefficients

γ(*)	0 in	ω_S	4.751 in²	ω_S*	-4.681 in²
ω_C	3.461 in²	ω_C*	-2.734 in²	γ_b	0

Results acc. 4.18.8.7 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'	545.5 psi	P_γ	0 psi
P_W	0 psi	P_{rim}	-25.23 psi	P_e	-99.77 psi

Step 7

Q_2	208.4 lbf	Q_3	-0.06861	F_m	0.03431

Strength condition for the tubesheet bending stress, case 1

σ =	14297 psi	< 1.5 · σ_B =	1.5·	*15800* psi	case 1-3
		< S_{PS} =		*47400* psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = 9299 psi

Step 9

F_{tmin}	-0.282	F_{tmax}	3.425		
x_{min}	2.445	x_{max}	6.587		
$\sigma_{T,1}$	-1309 psi	$\sigma_{T,2}$	2229 psi		

σ_{tmax} =	2229 psi	≤ σ_T =	*16700* psi	for calculation case 1-3
		≤2 · σ_T =	33400 psi	for calculation case 4-7

Tube weld force W_t = 326.2 lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t	0.3367 in	F_t	142.6	C_t	1.537	F_s	166.7

$\lvert\sigma_{tmin}\rvert$ =	-1309 psi	≤S_{tb} =	7141 psi	(only σ_{tmin} < 0 buckl.)

Buckling stability acc. 4.18.8.4 Step 9 satisfied

Step 10: Axial membrane stress σSm in the shell

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

$\sigma_{Sm} \le$ *0.85* **15800** psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **1781** psi ≤2· **15800** psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **1781** psi | < Min(**6749** psi , **43036** psi)

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

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

$\sigma_{Sm} \le$ *0.85* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 4.18.8.4 Step 10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}| =$ **14090** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

$\sigma_S =$ | **1781** psi | + | **-12309** psi | ≤ **23700** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}| =$ **34013** psi ≤1.5 · σ_{allC} or S_{PSc}

$\sigma_C =$ | **5568** psi | + | **28445** psi | ≤ **33600** psi

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

Minimum channel thickness with uniform thickness l_{Cm} **7.155** in

Strength condition 4.18.8.4 Step 11 is violated!

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

Modulus of elasticity	elastic	Option 3
Shell	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.83e+7** psi	**2.83e+7** psi

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

σ_S = **14090** psi ≤ ***47400*** psi =S_{PSs}

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

σ_C = **34013** psi ≤ ***67336*** psi =S_{PSc}

Geometric conditions:

valid

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

If: Tube sheet thickness= *1.5* in < *1* in

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

4.18.3: The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to 4.18.8.3 the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. 4.18.8 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
47400 psi = 3· ***15800*** psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 38.1\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 38.1\ \text{mm}$$

Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.3\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1467530\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2921\ \text{N/mm}$$

Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{34.92\ \text{mm}}{38.1\ \text{mm}} = 0.9167$$

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

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

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) \Leftrightarrow d_2^* = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186160\ \text{N/mm}^2}{182023\ \text{N/mm}^2} \cdot \frac{115.1\ \text{N/mm}^2}{108.9\ \text{N/mm}^2} \cdot 0.9167\right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75\ \text{mm} - 23.12\ \text{mm}}{31.75\ \text{mm}} = 0.2717$$

2 A188-2 - Fixed Tubesheets - ASME BPVC VIII-2, 2025

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

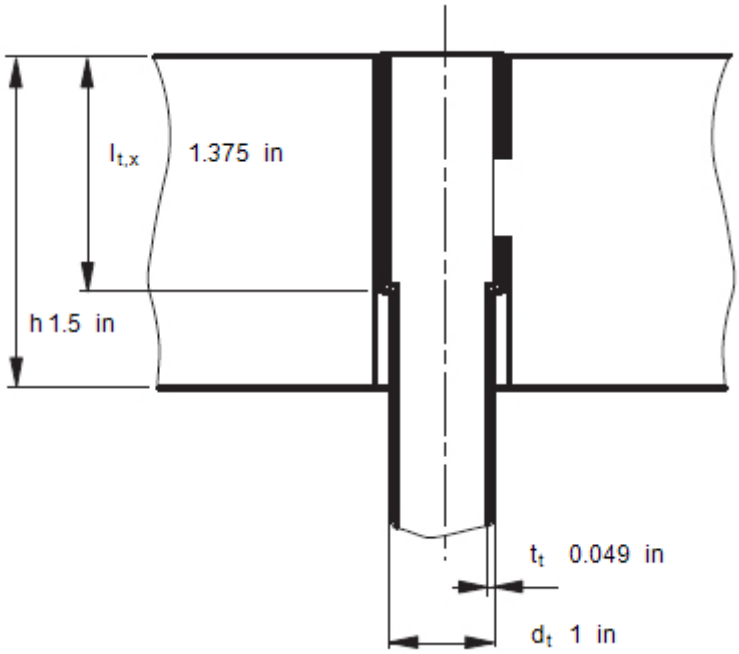
Configuration of the tubesheet (a, b, c, d)		Type	*a*	
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	
Internal operating pressure shell side		P_s	*325*	psi
Internal operating pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}		psi
Internal test pressure tube side		P_{tp}		psi
Load case	(1=operation, 2+3=test at 20°C, 4=other)		*1*	
load case: operation				
Calculation case per 4.18.8.4:	(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	*S30403-SA-240-304L*			
Tube material	*S30403-SA-249-TP304L*			
Shell material (Type abc)	*S30403-SA-240-304L*			
Channel material (Type a)	*K02700-SA-516-70*			

Operation	**Tubesheet**	**Tubes**	**Shell**	**Channel**
Temperature	*400* °F	*300* °F	*400* °F	*300* °F
Thickness	*1.5* in	*0.049* in	*0.5625* in	0.375 in
Outside diameter	*43.13* in	*1* in	*43.13* in	*42.88* in
Poiss.ratio	-	*0.31*	*0.31*	*0.3*
Allow. c1	0 mm	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in	0 in
Properties for the selected load case temperature				
Strength op	15864 psi	14185 psi	15864 psi	20015 psi
Safety op.	1	1	1	1
Modulus of elasticity	*2.64e+7* psi	*2.7e+7* psi	*2.64e+7* psi	*2.83e+7* psi
Therm.exp.	*9.462* 1E-6/°F	*9.217* 1E-6/°F	*9.462* 1E-6/°F	*6.885* 1E-6/°F
Yield str.	*17446* psi	*19184* psi	*17446* psi	*33668* psi
Limit temperature	1000 °F	1000 °F	1000 °F	1000 °F
All.stress	*15800* psi	*16700* psi	*15800* psi	*22400* psi
Pr.+sec.st	*47400* psi		*47400* psi	*67336* psi
Properties for testing at 20°C				
Strength	22191 psi	22191 psi	22191 psi	33939 psi
Safety	1	1	1	1
Yield str.	24656 psi	24656 psi	24656 psi	37710 psi
Tensile str.	70343 psi	70343 psi	70343 psi	70343 psi

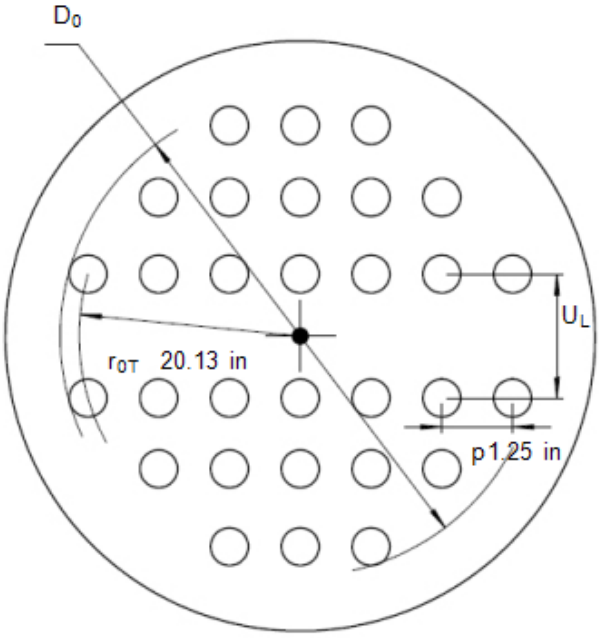
Additional specifications for the geometry and loading

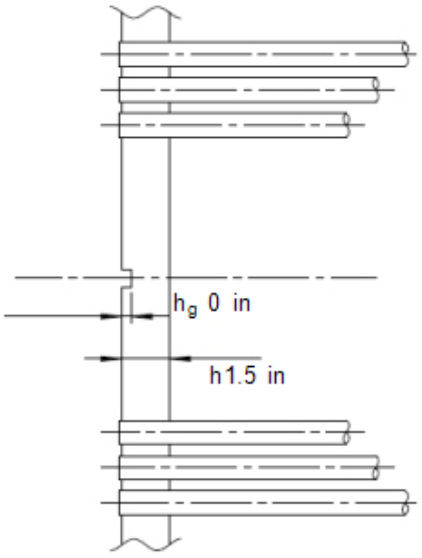
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	*1.375*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.9167**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*20.13*	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by C_p	Fig. 4.18.14	A_p		mm²
Tube pitch (center distance)		p	*1.25*	in





Total untubed area	UL1·LL1+UL2·LL2.. Fig. 4.18.3	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*237*	in
Unsupported tube span for buckling	l	*48*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*48*	in
Bellows inside diameter at its convolution height	D_j	*44.13*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*0.85*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.788*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.656*	1E-6/°F

4.18.8.7: 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'	*8.5*	1E-6/°F
Channel at T'_c	α'_c	*6.389*	1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*8.5*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		in

Maximum bolt force for all calculation cases	W_{max}	0	N

Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	***0.375***	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.13**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15765	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9104**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2717**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.439**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5436**	
Type abc: Coefficients for shell pressure	δ_S	**0.0927**	mm^3/N
β_S **0.3709** 1/in k_S **321305** lbf	λ_S	4.105e+7	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **0.4553** 1/in k_C **124455** lbf	λ_C	**1.786e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	8379598	lbf/in
Tube axial rigidity	K_t	16678	lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st}	0.5261	
Stiffness ratio Kj/(Ks+Kj)	J	1	

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2				E^*	7188365	psi
Ratio of elasticity tubesheet					E^*/E	0.2723	
effective Poisson's ratio tubesheet					v^*	0.3439	
Parameter for table 4.18.3					X_a	6.587	
Z_d 0.005244	Z_v 0.02338	Z_m 0.2202	Z_a 170.8		Z_w	0.02338	

Step 4

Diameter ratio = A/D0				K	1.045
F	5.484	Φ	7.37	Q_1	-0.0588
Q_{z1}	3.641	Q_{z2}	9.821	U	19.64

Step 5, coefficients

γ(*)	0 in	ω_S	4.751 in²	ω_S*	-4.681 in²
ω_C	3.461 in²	ω_C*	-2.734 in²	γ_b	0

Results acc. 4.18.8.7 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'	630.1 psi	P_t'	0 psi	P_γ	0 psi
P_W	0 psi	P_{rim}	70.2 psi	P_e	122.4 psi

Step 7

Q_2	-579.9 lbf	Q_3	-0.08105	F_m	0.04053

Strength condition for the tubesheet bending stress, case 2

σ =	20727 psi	< 1.5 · σ_B = 1.5·	*15800* psi	case 1-3	
		< S_{PS} =	*47400* psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = 9299 psi

Step 9

F_{tmin}	-0.2568	F_{tmax}	3.151
x_{min}	2.25	x_{max}	6.587
$\sigma_{T,1}$	1665 psi	$\sigma_{T,2}$	-2326 psi

σ_{tmax} =	2326 psi	≤ σ_T =	*16700* psi	for calculation case 1-3
		≤2 · σ_T =	33400 psi	for calculation case 4-7

Tube weld force W_t = 340.5 lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t	0.3367 in	F_t	142.6	C_t	1.674	F_s	166.7

$|\sigma_{tmin}|$ = | -2326 psi | ≤S_{tb} = 6558 psi (only σ_{tmin} < 0 buckl.)

Buckling stability acc. 4.18.8.4 Step 9 satisfied

Step 10: Axial membrane stress σSm in the shell

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

$\sigma_{Sm} \le$ *0.85* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **2387** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **2387** psi | < Min(**6749** psi , **43036** psi)

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

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

$\sigma_{Sm} \le$ *0.85* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 4.18.8.4 Step 10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}| =$ **30970** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

$\sigma_S =$ | **2387** psi | + | **28583** psi | ≤ **23700** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}| =$ **9242** psi ≤1.5 · σ_{allC} or S_{PSc}

$\sigma_C =$ | **0** psi | + | **-9242** psi | ≤ **33600** psi

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

Minimum channel thickness with uniform thickness l_{Cm} **7.155** in

Strength condition 4.18.8.4 Step 11 is violated!

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

Modulus of elasticity	elastic	Option 3
Shell	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.83e+7** psi	**2.83e+7** psi

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

σ_S = **30970** psi ≤ *47400* psi =S_{PSs}

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

σ_C = **9242** psi ≤ *67336* psi =S_{PSc}

Geometric conditions:

valid

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

If: Tube sheet thickness= *1.5* in < *1* in

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

4.18.3: The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to 4.18.8.3 the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. 4.18.8 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 38.1\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 38.1\ \text{mm}$$

Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.3\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1467530\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2921\ \text{N/mm}$$

Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{34.92\ \text{mm}}{38.1\ \text{mm}} = 0.9167$$

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

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

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) \Leftrightarrow d_2^* = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186160\ \text{N/mm}^2}{182023\ \text{N/mm}^2} \cdot \frac{115.1\ \text{N/mm}^2}{108.9\ \text{N/mm}^2} \cdot 0.9167\right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75\ \text{mm} - 23.12\ \text{mm}}{31.75\ \text{mm}} = 0.2717$$

2 A188-3 - Fixed Tubesheets - ASME BPVC VIII-2, 2025

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

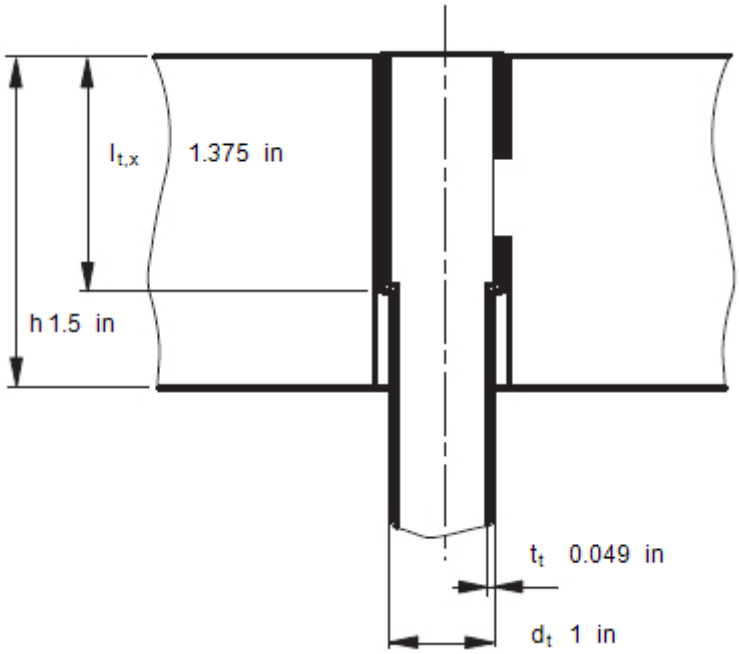
Configuration of the tubesheet (a, b, c, d)		Type	*a*	
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	
Internal operating pressure shell side		P_s	*325*	psi
Internal operating pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}		psi
Internal test pressure tube side		P_{tp}		psi
Load case	(1=operation, 2+3=test at 20°C, 4=other)		*1*	
load case: operation				
Calculation case per 4.18.8.4:	(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	*S30403-SA-240-304L*			
Tube material	*S30403-SA-249-TP304L*			
Shell material (Type abc)	*S30403-SA-240-304L*			
Channel material (Type a)	*K02700-SA-516-70*			

Operation	**Tubesheet**	**Tubes**	**Shell**	**Channel**
Temperature	*400* °F	*300* °F	*400* °F	*300* °F
Thickness	*1.5* in	*0.049* in	*0.5625* in	0.375 in
Outside diameter	*43.13* in	*1* in	*43.13* in	*42.88* in
Poiss.ratio	-	*0.31*	*0.31*	*0.3*
Allow. c1	0 mm	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in	0 in
Properties for the selected load case temperature				
Strength op	15864 psi	14185 psi	15864 psi	20015 psi
Safety op.	1	1	1	1
Modulus of elasticity	*2.64e+7* psi	*2.7e+7* psi	*2.64e+7* psi	*2.83e+7* psi
Therm.exp.	*9.462* 1E-6/°F	*9.217* 1E-6/°F	*9.462* 1E-6/°F	*6.885* 1E-6/°F
Yield str.	*17446* psi	*19184* psi	*17446* psi	*33668* psi
Limit temperature	1000 °F	1000 °F	1000 °F	1000 °F
All.stress	*15800* psi	*16700* psi	*15800* psi	*22400* psi
Pr.+sec.st	*47400* psi		*47400* psi	*67336* psi
Properties for testing at 20°C				
Strength	22191 psi	22191 psi	22191 psi	33939 psi
Safety	1	1	1	1
Yield str.	24656 psi	24656 psi	24656 psi	37710 psi
Tensile str.	70343 psi	70343 psi	70343 psi	70343 psi

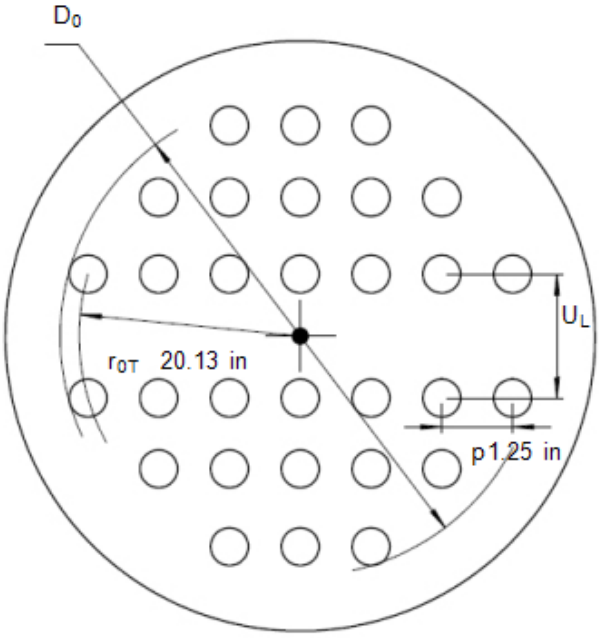
Additional specifications for the geometry and loading

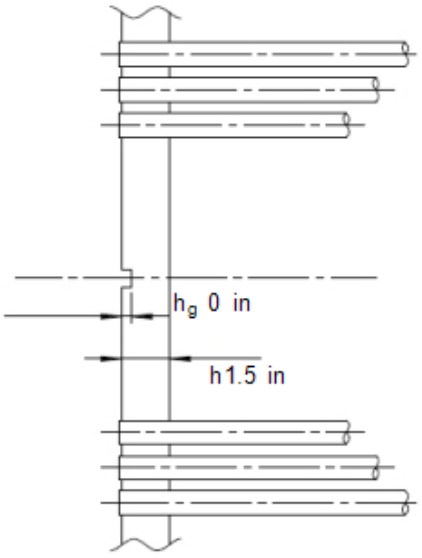
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	*1.375*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.9167**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*20.13*	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by C_p	Fig. 4.18.14	A_p		mm²
Tube pitch (center distance)		p	*1.25*	in





Total untubed area	UL1·LL1+UL2·LL2.. Fig. 4.18.3	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*237*	in
Unsupported tube span for buckling	l	*48*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*48*	in
Bellows inside diameter at its convolution height	D_j	*43.13*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*0.85*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.788*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.656*	1E-6/°F

4.18.8.7: 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'	*8.5*	1E-6/°F
Channel at T'_c	α'_c	*6.389*	1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*8.5*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		in

Maximum bolt force for all calculation cases	W_{max}	*0*	N

Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	***0.375***	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.13**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15765	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9104**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2717**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.439**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5436**	
Type abc: Coefficients for shell pressure	δ_S	**0.09269**	mm^3/N
β_S **0.3709** 1/in k_S **321314** lbf	λ_S	4.105e+7	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **0.4553** 1/in k_C **124455** lbf	λ_C	**1.786e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	8379105	lbf/in
Tube axial rigidity	K_t	16678	lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st}	0.5261	
Stiffness ratio Kj/(Ks+Kj)	J	1	

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2				E*	7188365	psi
Ratio of elasticity tubesheet					E*/E	0.2723	
effective Poisson's ratio tubesheet					v*	0.3439	
Parameter for table 4.18.3					X_a	6.587	
Z_d 0.005244	Z_v 0.02338	Z_m 0.2202	Z_a 170.8		Z_w	0.02338	

Step 4

Diameter ratio = A/D0					K	1.045	
F	5.484	Φ	7.37		Q_1	-0.05882	
Q_{z1}	3.641	Q_{z2}	9.816		U	19.63	

Step 5, coefficients

γ(*)	0	in	ω_S	4.751	in²	ω_S*	-4.681 in²
ω_C	3.461	in²	ω_C*	-2.721	in²	γ_b	0

Results acc. 4.18.8.7 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'	630.2	psi	P_t'	545.5	psi	P_γ	0 psi
P_W	0	psi	P_{rim}	45.07	psi	P_e	22.69 psi

Step 7

Q_2	-372.5	lbf	Q_3	-0.136		F_m	0.06798

Strength condition for the tubesheet bending stress, case 3

σ =	6443	psi	< 1.5 · σ_B =	1.5·	*15800*	psi	case 1-3
			< S_{PS} =		*47400*	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = 9299 psi

Step 9

F_{tmin}	-0.2187		F_{tmax}	2.115	
x_{min}	0.9221		x_{max}	6.191	
$\sigma_{T,1}$	372.3	psi	$\sigma_{T,2}$	-134.2	psi

σ_{tmax} =	372.3 psi	≤ σ_T =	*16700*	psi	for calculation case 1-3
		≤2 · σ_T =	33400	psi	for calculation case 4-7

Tube weld force W_t = 54.5 lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t	0.3367 in	F_t	142.6	C_t	2	F_s	166.7

$\lvert\sigma_{tmin}\rvert$ =	-134.2 psi	$\lvert$ ≤S_{tb} =	5490 psi	(only σ_{tmin} < 0 buckl.)

Buckling stability acc. 4.18.8.4 Step 9 satisfied

Step 10: Axial membrane stress σSm in the shell

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

$\sigma_{Sm} \le$ *0.85* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **4169** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **4169** psi | < Min(**6749** psi , **43039** psi)

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

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

$\sigma_{Sm} \le$ *0.85* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 4.18.8.4 Step 10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **20429** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **4169** psi | + | **16260** psi | ≤ **23700** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **24783** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **5568** psi | + | **19215** psi | ≤ **33600** psi

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

Minimum channel thickness with uniform thickness l_{Cm} **7.155** in

Strength condition 4.18.8.4 Step 11 is satisfied.

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

Modulus of elasticity	elastic	Option 3
Shell	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.83e+7** psi	**2.83e+7** psi

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

σ_S = **20429** psi ≤ *47400* psi $=S_{PSs}$

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

σ_C = **24783** psi ≤ *67336* psi $=S_{PSc}$

Geometric conditions:

valid

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

If: Tube sheet thickness= *1.5* in < *1* in

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

4.18.3: The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to 4.18.8.3 the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. 4.18.8 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 38.1\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 38.1\ \text{mm}$$

Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.3\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1467444\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2921\ \text{N/mm}$$

Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{34.92\ \text{mm}}{38.1\ \text{mm}} = 0.9167$$

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

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

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) \Leftrightarrow d_2^* = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186160\ \text{N/mm}^2}{182023\ \text{N/mm}^2} \cdot \frac{115.1\ \text{N/mm}^2}{108.9\ \text{N/mm}^2} \cdot 0.9167\right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75\ \text{mm} - 23.12\ \text{mm}}{31.75\ \text{mm}} = 0.2717$$

2 A188-4 - Fixed Tubesheets - ASME BPVC VIII-2, 2025

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

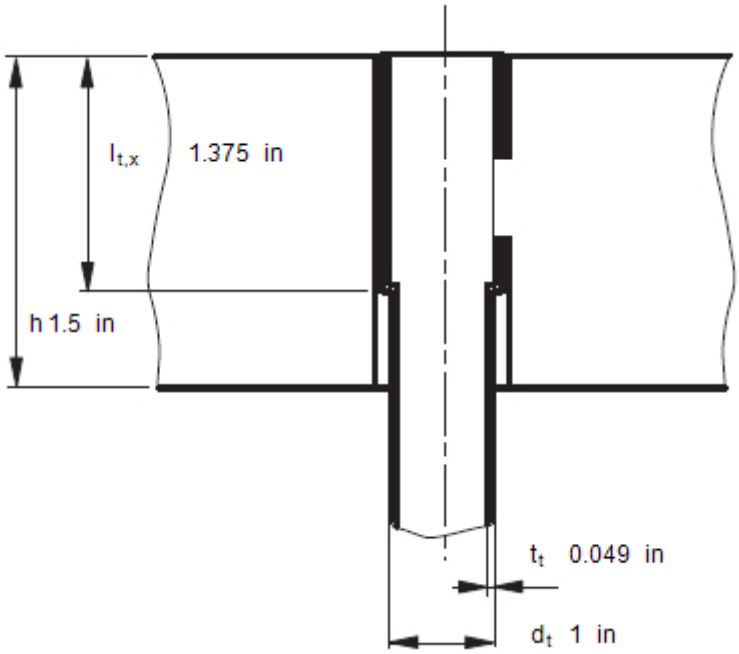
Configuration of the tubesheet (a, b, c, d)		Type	*a*	
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	
Internal operating pressure shell side		P_s	*325*	psi
Internal operating pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}		psi
Internal test pressure tube side		P_{tp}		psi
Load case	(1=operation, 2+3=test at 20°C, 4=other)		*1*	
load case: operation				
Calculation case per 4.18.8.4:	(1-D1), (2-D2), (3-D3), (4-O4), (5-O1), (6-O2), (7-O3)		4	
Differential thermal expansion only (Ps=Pt=0)				
Tubesheet material	*S30403-SA-240-304L*			
Tube material	*S30403-SA-249-TP304L*			
Shell material (Type abc)	*S30403-SA-240-304L*			
Channel material (Type a)	*K02700-SA-516-70*			

Operation	**Tubesheet**	**Tubes**	**Shell**	**Channel**
Temperature	*400* °F	*300* °F	*400* °F	*300* °F
Thickness	*1.5* in	*0.049* in	*0.5625* in	0.375 in
Outside diameter	*43.13* in	*1* in	*43.13* in	*42.88* in
Poiss.ratio	-	*0.31*	*0.31*	*0.3*
Allow. c1	0 mm	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in	0 in
Properties for the selected load case temperature				
Strength op	15864 psi	14185 psi	15864 psi	20015 psi
Safety op.	1	1	1	1
Modulus of elasticity	*2.64e+7* psi	*2.7e+7* psi	*2.64e+7* psi	*2.83e+7* psi
Therm.exp.	*9.462* 1E-6/°F	*9.217* 1E-6/°F	*9.462* 1E-6/°F	*6.885* 1E-6/°F
Yield str.	*17446* psi	*19184* psi	*17446* psi	*33668* psi
Limit temperature	1000 °F	1000 °F	1000 °F	1000 °F
All.stress	*15800* psi	*16700* psi	*15800* psi	*22400* psi
Pr.+sec.st	*47400* psi		*47400* psi	*67336* psi
Properties for testing at 20°C				
Strength	22191 psi	22191 psi	22191 psi	33939 psi
Safety	1	1	1	1
Yield str.	24656 psi	24656 psi	24656 psi	37710 psi
Tensile str.	70343 psi	70343 psi	70343 psi	70343 psi

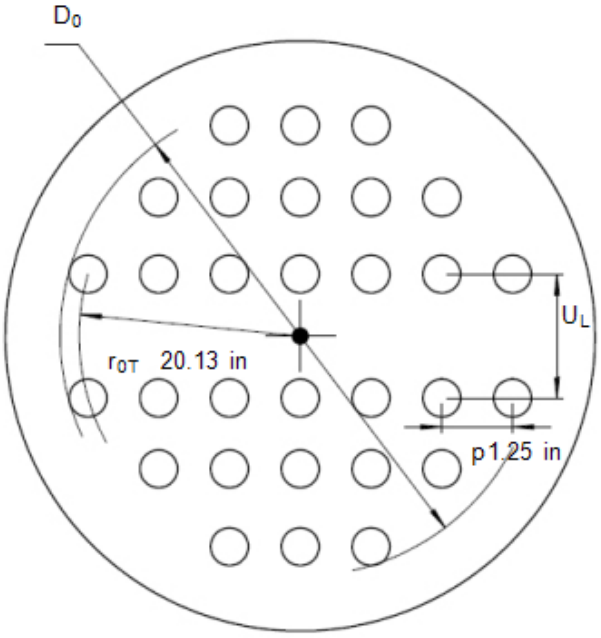
Additional specifications for the geometry and loading

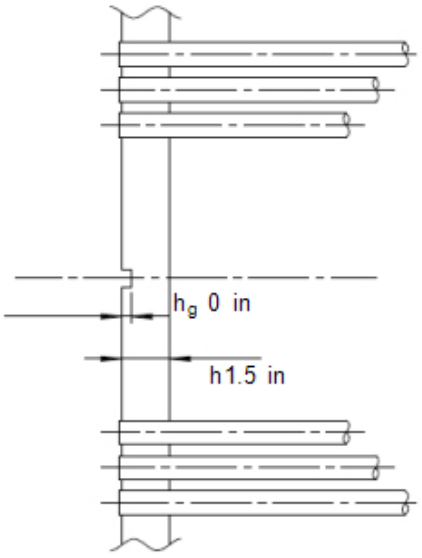
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	*1.375*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.9167**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*20.13*	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by C_p	Fig. 4.18.14	A_p		mm²
Tube pitch (center distance)		p	*1.25*	in





Total untubed area	UL1·LL1+UL2·LL2.. Fig. 4.18.3	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*237*	in
Unsupported tube span for buckling	l	*48*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*48*	in
Bellows inside diameter at its convolution height	D_j	*43.13*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*0.85*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.802*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.652*	1E-6/°F

4.18.8.7: 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'	*8.5*	1E-6/°F
Channel at T'_c	α'_c	*6.389*	1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*8.5*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		in

Maximum bolt force for all calculation cases	W_{max}	*0*	N

Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	***0.375***	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.13**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15765	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9104**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2717**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.439**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5436**	
Type abc: Coefficients for shell pressure	δ_S	**0.09269**	mm^3/N
β_S **0.3709** 1/in k_S **321314** lbf	λ_S	4.105e+7	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **0.4553** 1/in k_C **124455** lbf	λ_C	**1.786e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	**8379105**	lbf/in
Tube axial rigidity	K_t	**16678**	lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st}	**0.5261**	
Stiffness ratio Kj/(Ks+Kj)	J	**1**	

Step 3

Effective modulus of el. tubesheet (Fig. 4.18.1-2)	E*	**7188365**	psi
Ratio of elasticity tubesheet	E*/E	**0.2723**	
effective Poisson's ratio tubesheet	v*	**0.3439**	
Parameter for table 4.18.3	X_a	**6.587**	

Z_d	Z_v	Z_m	Z_a	Z_w
0.005244	**0.02338**	**0.2202**	**170.8**	**0.02338**

Step 4

Diameter ratio = A/D0				K	**1.045**
F	**5.484**	Φ	**7.37**	Q_1	**-0.05882**
Q_{z1}	**3.641**	Q_{z2}	**9.816**	U	**19.63**

Step 5, coefficients

γ(*)	**-0.08087** in	ω_S	**4.751** in²	ω_S*	**-4.681** in²
ω_C	**3.461** in²	ω_C*	**-2.721** in²	γ_b	**0**

Results acc. 4.18.8.7 Radial differential thermal expansion

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

Step 6

P_s'	**0** psi	P_t'	**0** psi	P_γ	**-963.4** psi
P_W	**0** psi	P_{rim}	**0** psi	P_e	**-168.5** psi

Step 7

Q_2	**0** lbf	Q_3	**-0.05882**	F_m	**0.02941**

Strength condition for the tubesheet bending stress, case 4

σ =	**20693** psi	< 1.5 · σ_B = 1.5·	*15800* psi		case 1-3
		< S_{PS} =	*47400* psi		case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = **9299** psi

Step 9

F_{tmin}	**-0.306**	F_{tmax}	**3.641**
x_{min}	**2.587**	x_{max}	**6.587**
$\sigma_{T,1}$	**-493** psi	$\sigma_{T,2}$	**5865** psi

σ_{tmax} =	**5865** psi	≤ σ_T =	*16700* psi	for calculation case 1-3
		≤2 · σ_T =	**33400** psi	for calculation case 4-7

Tube weld force W_t = **858.7** lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t	**0.3367** in	F_t	**142.6**	C_t	**1.43**	F_s	**166.7**

$\lvert\sigma_{tmin}\rvert$ =	**-493** psi	≤S_{tb} =	**7680** psi

(only σ_{tmin} < 0 buckl.)

Buckling stability acc. 4.18.8.4 Step 9 satisfied

Step 10: Axial membrane stress σSm in the shell

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

$\sigma_{Sm} \le$ *0.85* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **-2994** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **-2994** psi | < Min(**6749** psi , **43039** psi)

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

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

$\sigma_{Sm} \le$ *0.85* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 4.18.8.4 Step 10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}| =$ **29195** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

$\sigma_S =$ | **-2994** psi | + | **-26201** psi | ≤ **47400** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}| =$ **23965** psi ≤1.5 · σ_{allC} or S_{PSc}

$\sigma_C =$ | **0** psi | + | **23965** psi | ≤ **67336** psi

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

Minimum channel thickness with uniform thickness l_{Cm} **7.155** in

Strength condition 4.18.8.4 Step 11 is satisfied

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

Modulus of elasticity	elastic	Option 3
Shell	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.83e+7** psi	**2.83e+7** psi

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

σ_S = **29195** psi ≤ *47400* psi $= S_{PSs}$

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

σ_C = **23965** psi ≤ *67336* psi $= S_{PSc}$

Geometric conditions:

valid

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

If: Tube sheet thickness= *1.5* in < *1* in

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

4.18.3: The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to 4.18.8.3 the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. 4.18.8 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 38.1\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 38.1\ \text{mm}$$

Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.3\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1467444\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2921\ \text{N/mm}$$

Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{34.92\ \text{mm}}{38.1\ \text{mm}} = 0.9167$$

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

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

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) \Leftrightarrow d_2^* = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186160\ \text{N/mm}^2}{182023\ \text{N/mm}^2} \cdot \frac{115.1\ \text{N/mm}^2}{108.9\ \text{N/mm}^2} \cdot 0.9167\right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75\ \text{mm} - 23.12\ \text{mm}}{31.75\ \text{mm}} = 0.2717$$

2 A188-5 - Fixed Tubesheets - ASME BPVC VIII-2, 2025

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

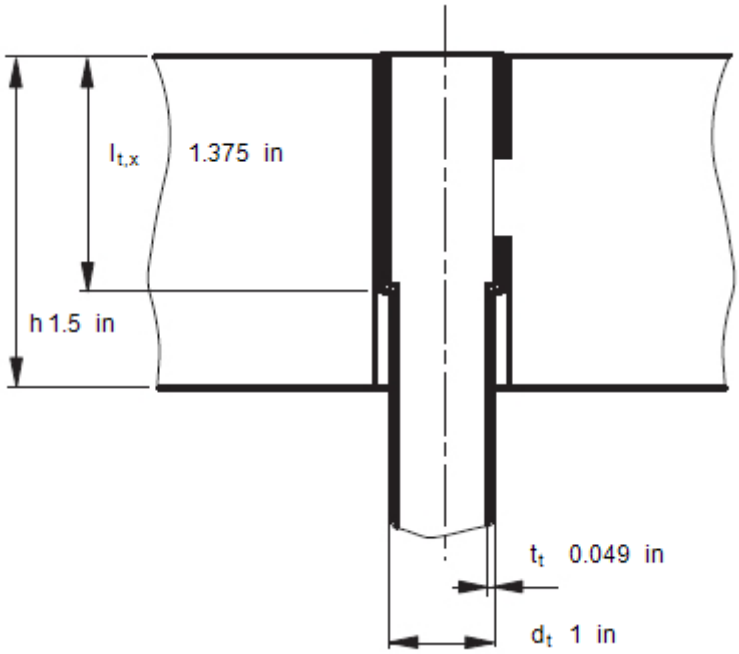
Configuration of the tubesheet (a, b, c, d)		Type	*a*	
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	
Internal operating pressure shell side		P_s	*325*	psi
Internal operating pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}		psi
Internal test pressure tube side		P_{tp}		psi
Load case	(1=operation, 2+3=test at 20°C, 4=other)		*1*	
load case: operation				
Calculation case per 4.18.8.4:	(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	*S30403-SA-240-304L*			
Tube material	*S30403-SA-249-TP304L*			
Shell material (Type abc)	*S30403-SA-240-304L*			
Channel material (Type a)	*K02700-SA-516-70*			

Operation	**Tubesheet**	**Tubes**	**Shell**	**Channel**
Temperature	*400* °F	*300* °F	*400* °F	*300* °F
Thickness	*1.5* in	*0.049* in	*0.5625* in	0.375 in
Outside diameter	*43.13* in	*1* in	*43.13* in	*42.88* in
Poiss.ratio	-	*0.31*	*0.31*	*0.3*
Allow. c1	0 mm	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in	0 in
Properties for the selected load case temperature				
Strength op	15864 psi	14185 psi	15864 psi	20015 psi
Safety op.	1	1	1	1
Modulus of elasticity	*2.64e+7* psi	*2.7e+7* psi	*2.64e+7* psi	*2.83e+7* psi
Therm.exp.	*9.462* 1E-6/°F	*9.217* 1E-6/°F	*9.462* 1E-6/°F	*6.885* 1E-6/°F
Yield str.	*17446* psi	*19184* psi	*17446* psi	*33668* psi
Limit temperature	1000 °F	1000 °F	1000 °F	1000 °F
All.stress	*15800* psi	*16700* psi	*15800* psi	*22400* psi
Pr.+sec.st	*47400* psi		*47400* psi	*67336* psi
Properties for testing at 20°C				
Strength	22191 psi	22191 psi	22191 psi	33939 psi
Safety	1	1	1	1
Yield str.	24656 psi	24656 psi	24656 psi	37710 psi
Tensile str.	70343 psi	70343 psi	70343 psi	70343 psi

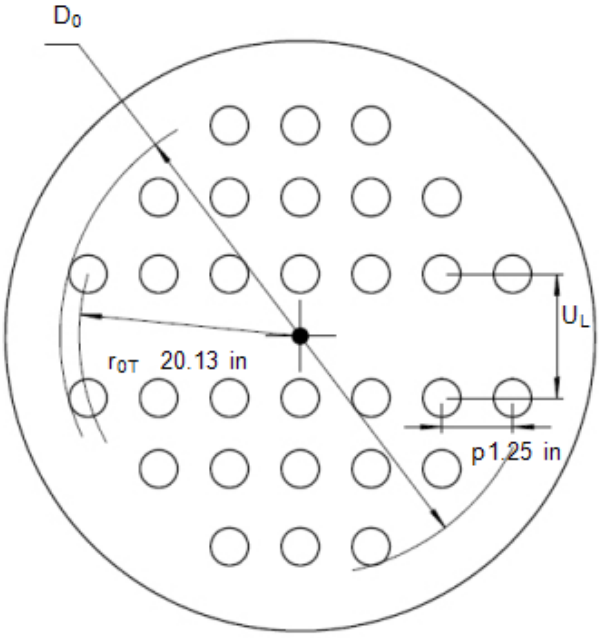
Additional specifications for the geometry and loading

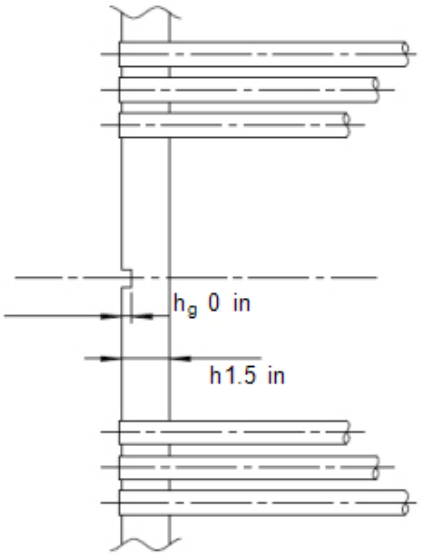
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	*1.375*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.9167**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*20.13*	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by C_p	Fig. 4.18.14	A_p		mm²
Tube pitch (center distance)		p	*1.25*	in





Total untubed area	UL1·LL1+UL2·LL2.. Fig. 4.18.3	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*237*	in
Unsupported tube span for buckling	l	*48*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*48*	in
Bellows inside diameter at its convolution height	D_j	*43.13*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*0.85*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.788*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.656*	1E-6/°F

4.18.8.7: 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'	*8.5*	1E-6/°F
Channel at T'_c	α'_c	*6.389*	1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*8.5*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		in

Maximum bolt force for all calculation cases	W_{max}	*0*	N

Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	***0.375***	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.13**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15765	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9104**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2717**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.439**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5436**	
Type abc: Coefficients for shell pressure	δ_S	**0.09269**	mm^3/N
β_S **0.3709** 1/in k_S **321314** lbf	λ_S	4.105e+7	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **0.4553** 1/in k_C **124455** lbf	λ_C	**1.786e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	8379105	lbf/in
Tube axial rigidity	K_t	16678	lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st}	0.5261	
Stiffness ratio Kj/(Ks+Kj)	J	1	

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2				E^*	7188365	psi
Ratio of elasticity tubesheet					E^*/E	0.2723	
effective Poisson's ratio tubesheet					v^*	0.3439	
Parameter for table 4.18.3					X_a	6.587	
Z_d 0.005244	Z_v 0.02338	Z_m 0.2202	Z_a 170.8		Z_w	0.02338	

Step 4

Diameter ratio = A/D0				K	1.045
F	5.484	Φ	7.37	Q_1	-0.05882
Q_{z1}	3.641	Q_{z2}	9.816	U	19.63

Step 5, coefficients

γ(*)	-0.08055 in	ω_S	4.751 in²	ω_S*	-4.681 in²
ω_C	3.461 in²	ω_C*	-2.721 in²	γ_b	0

Results acc. 4.18.8.7 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'	545.5 psi	P_γ	-959.6 psi
P_W	0 psi	P_{rim}	-25.1 psi	P_e	-267.6 psi

Step 7

Q_2	207.4 lbf	Q_3	-0.06246	F_m	0.03123

Strength condition for the tubesheet bending stress, case 5

σ =	34905 psi	< 1.5 · σ_B = 1.5·	*15800* psi	case 1-3	
		< S_{PS} =	*47400* psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = 9299 psi

Step 9

F_{tmin}	-0.2967	F_{tmax}	3.561
x_{min}	2.535	x_{max}	6.587
$\sigma_{T,1}$	-1799 psi	$\sigma_{T,2}$	8071 psi

σ_{tmax} =	8071 psi	≤ σ_T =	*16700* psi	for calculation case 1-3
		≤2 · σ_T =	33400 psi	for calculation case 4-7

Tube weld force W_t = 1182 lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t 0.3367 in F_t 142.6 C_t 1.47 F_s 166.7

$|\sigma_{tmin}|$ = | -1799 psi | ≤S_{tb} = 7470 psi (only σ_{tmin} < 0 buckl.)

Buckling stability acc. 4.18.8.4 Step 9 satisfied

Step 10: Axial membrane stress σSm in the shell

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

$\sigma_{Sm} \le$ *0.85* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **-1201** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **-1201** psi | < Min(**6749** psi , **43039** psi)

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

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

$\sigma_{Sm} \le$ *0.85* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 4.18.8.4 Step 10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **39616** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-1201** psi | + | **-38415** psi | ≤ **47400** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **57891** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **5568** psi | + | **52323** psi | ≤ **67336** psi

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

Minimum channel thickness with uniform thickness l_{Cm} **7.155** in

Strength condition 4.18.8.4 Step 11 is satisfied

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

Modulus of elasticity	elastic	Option 3
Shell	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.83e+7** psi	**2.83e+7** psi

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

σ_S = **39616** psi ≤ *47400* psi $= S_{PSs}$

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

σ_C = **57891** psi ≤ *67336* psi $= S_{PSc}$

Geometric conditions:

valid

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

If: Tube sheet thickness= *1.5* in < *1* in

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

4.18.3: The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to 4.18.8.3 the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. 4.18.8 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 38.1\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 38.1\ \text{mm}$$

Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.3\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1467444\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2921\ \text{N/mm}$$

Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{34.92\ \text{mm}}{38.1\ \text{mm}} = 0.9167$$

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

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

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) \Leftrightarrow d_2^* = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186160\ \text{N/mm}^2}{182023\ \text{N/mm}^2} \cdot \frac{115.1\ \text{N/mm}^2}{108.9\ \text{N/mm}^2} \cdot 0.9167\right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75\ \text{mm} - 23.12\ \text{mm}}{31.75\ \text{mm}} = 0.2717$$

2 A188-6 - Fixed Tubesheets - ASME BPVC VIII-2, 2025

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

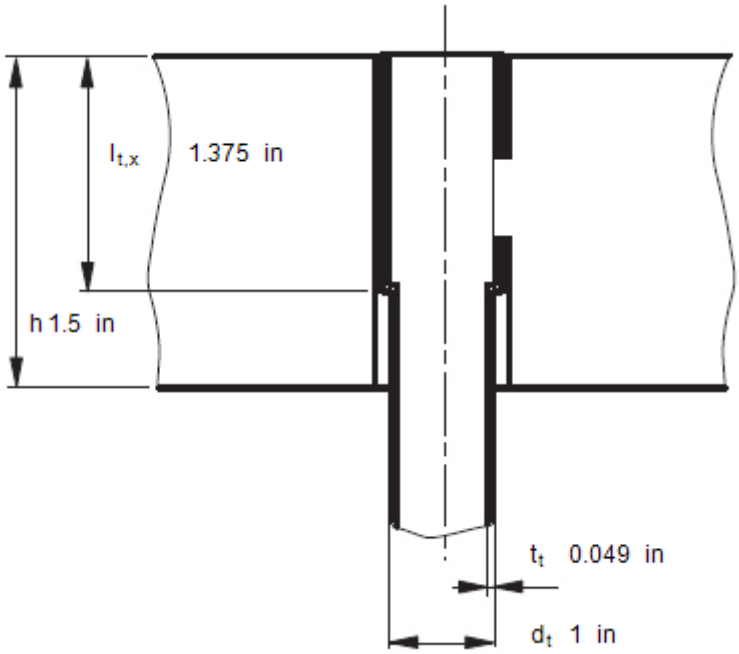
Configuration of the tubesheet (a, b, c, d)		Type	*a*	
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	
Internal operating pressure shell side		P_s	*325*	psi
Internal operating pressure tube side		P_t	*200*	psi
Internal test pressure shell side		P_{sp}		psi
Internal test pressure tube side		P_{tp}		psi
Load case	(1=operation, 2+3=test at 20°C, 4=other)		*1*	
load case: operation				
Calculation case per 4.18.8.4:	(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	*S30403-SA-240-304L*			
Tube material	*S30403-SA-249-TP304L*			
Shell material (Type abc)	*S30403-SA-240-304L*			
Channel material (Type a)	*K02700-SA-516-70*			

Operation	**Tubesheet**	**Tubes**	**Shell**	**Channel**
Temperature	*400* °F	*300* °F	*400* °F	*300* °F
Thickness	*1.5* in	*0.049* in	*0.5625* in	0.375 in
Outside diameter	*43.13* in	*1* in	*43.13* in	*42.88* in
Poiss.ratio	-	*0.31*	*0.31*	*0.3*
Allow. c1	0 mm	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in	0 in
Properties for the selected load case temperature				
Strength op	15864 psi	14185 psi	15864 psi	20015 psi
Safety op.	1	1	1	1
Modulus of elasticity	*2.64e+7* psi	*2.7e+7* psi	*2.64e+7* psi	*2.83e+7* psi
Therm.exp.	*9.462* 1E-6/°F	*9.217* 1E-6/°F	*9.462* 1E-6/°F	*6.885* 1E-6/°F
Yield str.	*17446* psi	*19184* psi	*17446* psi	*33668* psi
Limit temperature	1000 °F	1000 °F	1000 °F	1000 °F
All.stress	*15800* psi	*16700* psi	*15800* psi	*22400* psi
Pr.+sec.st	*47400* psi		*47400* psi	*67336* psi
Properties for testing at 20°C				
Strength	22191 psi	22191 psi	22191 psi	33939 psi
Safety	1	1	1	1
Yield str.	24656 psi	24656 psi	24656 psi	37710 psi
Tensile str.	70343 psi	70343 psi	70343 psi	70343 psi

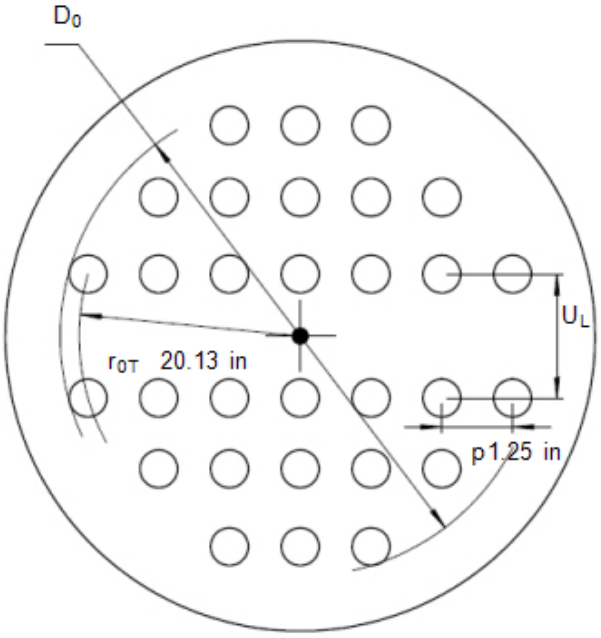
Additional specifications for the geometry and loading

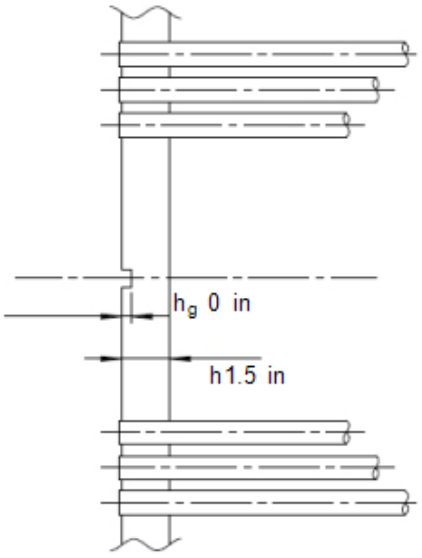
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	*1.375*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.9167**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*20.13*	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by C_p	Fig. 4.18.14	A_p		mm²
Tube pitch (center distance)		p	*1.25*	in





Total untubed area	UL1·LL1+UL2·LL2.. Fig. 4.18.3	A_L	*0*	in²
Depth of tube side pass partition groove		h_g	*0*	in

Tube length between inner tubesheet faces	L	*237*	in
Unsupported tube span for buckling	l	*48*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*48*	in
Bellows inside diameter at its convolution height	D_j	*43.13*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*1e+38*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*0.85*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*151*	°F
Mean temperature along the tube length	T_{tm}	*113*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*8.788*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*8.656*	1E-6/°F

4.18.8.7: 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'	*8.5*	1E-6/°F
Channel at T'_c	α'_c	*6.389*	1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*8.5*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		in

Maximum bolt force for all calculation cases	W_{max}	*0*	N

Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	***0.375***	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.13**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15765	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9104**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2717**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.439**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5436**	
Type abc: Coefficients for shell pressure	δ_S	**0.09269**	mm^3/N
β_S **0.3709** 1/in k_S **321314** lbf	λ_S	4.105e+7	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **0.4553** 1/in k_C **124455** lbf	λ_C	**1.786e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	8379105	lbf/in
Tube axial rigidity	K_t	16678	lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st}	0.5261	
Stiffness ratio Kj/(Ks+Kj)	J	1	

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2				E^*	7188365	psi
Ratio of elasticity tubesheet					E^*/E	0.2723	
effective Poisson's ratio tubesheet					v^*	0.3439	
Parameter for table 4.18.3					X_a	6.587	
Z_d 0.005244	Z_v 0.02338	Z_m 0.2202	Z_a 170.8		Z_w	0.02338	

Step 4

Diameter ratio = A/D0				K	1.045
F	5.484	Φ	7.37	Q_1	-0.05882
Q_{z1}	3.641	Q_{z2}	9.816	U	19.63

Step 5, coefficients

γ(*)	-0.08055 in	ω_S	4.751 in²	ω_S*	-4.681 in²
ω_C	3.461 in²	ω_C*	-2.721 in²	γ_b	0

Results acc. 4.18.8.7 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'	630.2 psi	P_t'	0 psi	P_γ	-959.6 psi
P_W	0 psi	P_{rim}	70.17 psi	P_e	-45.33 psi

Step 7

Q_2	-579.9 lbf	Q_3	0.001302	F_m	0.03732

Strength condition for the tubesheet bending stress, case 6

σ =	7067 psi	< 1.5 · σ_B = 1.5·	*15800* psi	case 1-3	
		< S_{PS} =	*47400* psi	case 4-7	

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = 9299 psi

Step 9

F_{tmin}	-0.5189	F_{tmax}	4.964
x_{min}	3.188	x_{max}	6.587
$\sigma_{T,1}$	1140 psi	$\sigma_{T,2}$	3516 psi

σ_{tmax} =	3516 psi	≤ σ_T =	*16700* psi	for calculation case 1-3
		≤2 · σ_T =	33400 psi	for calculation case 4-7

Tube weld force W_t = 514.8 lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t	0.3367 in	F_t	142.6	C_t	1.25	F_s	166.7

$\lvert\sigma_{tmin}\rvert$ =	1140 psi	≤S_{tb} =	8783 psi	(only σ_{tmin} < 0 buckl.)

Strength acc. 4.18.8.4 Step 9 satisfied

Step 10: Axial membrane stress σSm in the shell

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

$\sigma_{Sm} \le$ *0.85* *15800* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **-595.2** psi ≤2· *15800* psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **-595.2** psi | < Min(**6749** psi , **43039** psi)

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

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

$\sigma_{Sm} \le$ *0.85* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 4.18.8.4 Step 10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **3074** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

σ_S = | **-595.2** psi | + | **2479** psi | ≤ **47400** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = **14634** psi ≤1.5 · σ_{allC} or S_{PSc}

σ_C = | **0** psi | + | **14634** psi | ≤ **67336** psi

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

Minimum channel thickness with uniform thickness l_{Cm} **7.155** in

Strength condition 4.18.8.4 Step 11 is satisfied

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

Modulus of elasticity	elastic	Option 3
Shell	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.83e+7** psi	**2.83e+7** psi

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

σ_S = **3074** psi ≤ *47400* psi $= S_{PSs}$

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

σ_C = **14634** psi ≤ *67336* psi $= S_{PSc}$

Geometric conditions:

valid

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

If: Tube sheet thickness= *1.5* in < *1* in

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

4.18.3: The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to 4.18.8.3 the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. 4.18.8 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
47400 psi = 3· *15800* psi or 2· *17446* psi
(b) under the condition: SigZul not in the creep range:
T= **400** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 38.1\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 38.1\ \text{mm}$$

Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.3\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1467444\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2921\ \text{N/mm}$$

Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{34.92\ \text{mm}}{38.1\ \text{mm}} = 0.9167$$

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

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

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) \Leftrightarrow d_2^* = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186160\ \text{N/mm}^2}{182023\ \text{N/mm}^2} \cdot \frac{115.1\ \text{N/mm}^2}{108.9\ \text{N/mm}^2} \cdot 0.9167\right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75\ \text{mm} - 23.12\ \text{mm}}{31.75\ \text{mm}} = 0.2717$$

2 A188-7 - Fixed Tubesheets - ASME BPVC VIII-2, 2025

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

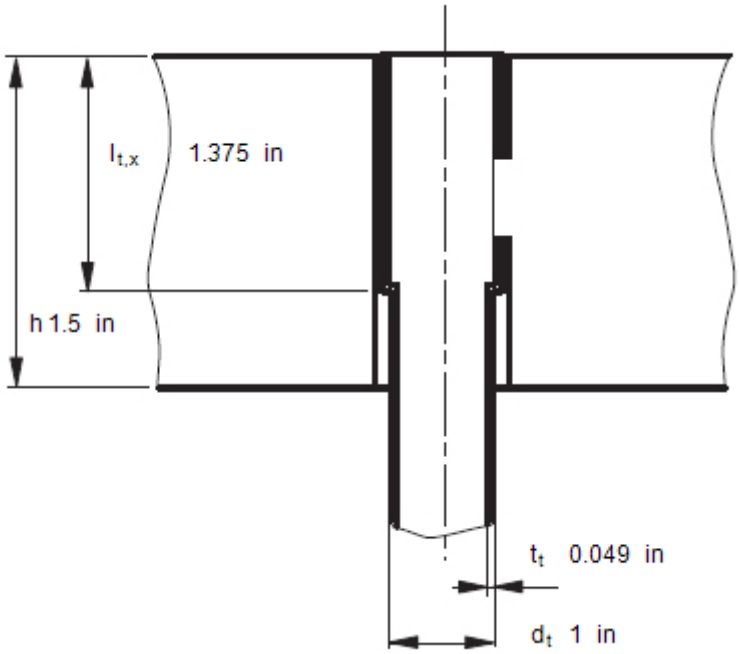
Configuration of the tubesheet (a, b, c, d)		Type	a	
Tubesheet integral with shell and channel				
Channel type (1=Cylinder, 2=Hemispherical)			1	
Internal operating pressure shell side		P_s	325	psi
Internal operating pressure tube side		P_t	200	psi
Internal test pressure shell side		P_{sp}		psi
Internal test pressure tube side		P_{tp}		psi
Load case	(1=operation, 2+3=test at 20°C, 4=other)		1	
load case: operation				
Calculation case per 4.18.8.4:	(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	S30403-SA-240-304L			
Tube material	S30403-SA-249-TP304L			
Shell material (Type abc)	S30403-SA-240-304L			
Channel material (Type a)	K02700-SA-516-70			

Operation	**Tubesheet**	**Tubes**	**Shell**	**Channel**
Temperature	400 °F	300 °F	400 °F	300 °F
Thickness	1.5 in	0.049 in	0.5625 in	0.375 in
Outside diameter	43.13 in	1 in	43.13 in	42.88 in
Poiss.ratio	-	0.31	0.31	0.3
Allow. c1	0 mm	0 in	0 in	0 in
Corros. all. c_2	0 in	0 in	0 in	0 in
Properties for the selected load case temperature				
Strength op	15864 psi	14185 psi	15864 psi	20015 psi
Safety op.	1	1	1	1
Modulus of elasticity	2.64e+7 psi	2.7e+7 psi	2.64e+7 psi	2.83e+7 psi
Therm.exp.	9.462 1E-6/°F	9.217 1E-6/°F	9.462 1E-6/°F	6.885 1E-6/°F
Yield str.	17446 psi	19184 psi	17446 psi	33668 psi
Limit temperature	1000 °F	1000 °F	1000 °F	1000 °F
All.stress	15800 psi	16700 psi	15800 psi	22400 psi
Pr.+sec.st	47400 psi		47400 psi	67336 psi
Properties for testing at 20°C				
Strength	22191 psi	22191 psi	22191 psi	33939 psi
Safety	1	1	1	1
Yield str.	24656 psi	24656 psi	24656 psi	37710 psi
Tensile str.	70343 psi	70343 psi	70343 psi	70343 psi

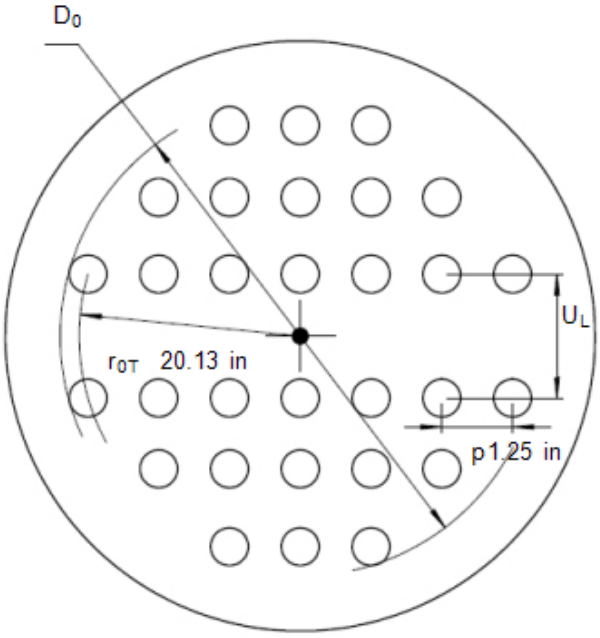
Additional specifications for the geometry and loading

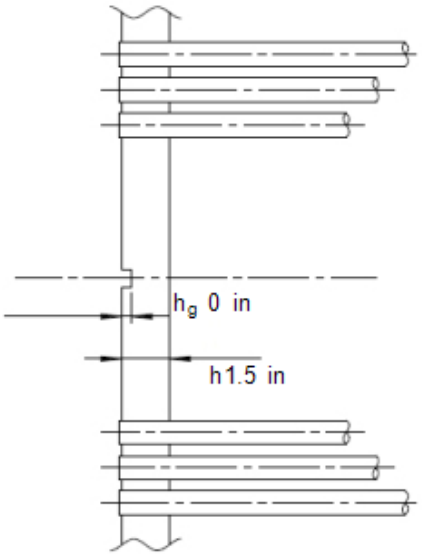
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	1.375 in
Expanded length ratio $l_{t,x}/h$		ρ	**0.9167**
Radius to outermost tube hole center	Fig. 4.18.2a	r_{OT}	20.13 in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p	in
Total area enclosed by C_p	Fig. 4.18.14	A_p	mm²
Tube pitch (center distance)		p	1.25 in





Total untubed area	UL1·LL1+UL2·LL2.. Fig. 4.18.3	A_L	0 in²
Depth of tube side pass partition groove		h_g	0 in

Tube length between inner tubesheet faces	L	237	in
Unsupported tube span for buckling	l	48	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	48	in
Bellows inside diameter at its convolution height	D_j	43.13	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	1e+38	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	0.85	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	151	°F
Mean temperature along the tube length	T_{tm}	113	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	8.788	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	8.656	1E-6/°F

4.18.8.7: 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'	8.5	1E-6/°F
Channel at T'_c	α'_c	6.389	1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	8.5	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in		in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
A_m < actual bolt area =					
Tubesheet flange thickness	h_r	**0**	in		in

Maximum bolt force for all calculation cases	W_{max}	0	N

Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**0**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**1**	
Channel shell thickness without allowances	t_c	**0.375**	in
Shell thickness without allowances	t_s	**0.5625**	in
Channel inside diameter corroded (type a)	D_c	**42.13**	in
Shell inside diameter corroded (type abc)	D_s	**42.01**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4			
Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.64e+7	psi
Tube material allowable stress basis at T	K_{tT}	15765	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.9104**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2717**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**20.63**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**21.06**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**21**	in
Ratio = ac/a0	ρ_C	**1.021**	
Ratio = as/a0	ρ_S	**1.018**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.439**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.5436**	
Type abc: Coefficients for shell pressure	δ_S	**0.09269**	mm^3/N
β_S **0.3709** 1/in k_S **321314** lbf	λ_S	4.105e+7	psi
Type a: Coefficients for channel pressure	δ_c	**0.1309**	mm^3/N
β_C **0.4553** 1/in k_C **124455** lbf	λ_C	**1.786e+7**	psi

Step 2

Shell axial rigidity K_s or K_s*	K_s	8379105	lbf/in
Tube axial rigidity	K_t	16678	lbf/in
Stiffness ratio $K_s/(N_t \cdot K_t)$	K_{st}	0.5261	
Stiffness ratio Kj/(Ks+Kj)	J	1	

Step 3

Effective modulus of el. tubesheet			Fig. 4.18.1-2				E^*	7188365	psi
Ratio of elasticity tubesheet							E^*/E	0.2723	
effective Poisson's ratio tubesheet							v^*	0.3439	
Parameter for table 4.18.3							X_a	6.587	
Z_d	0.005244	Z_v	0.02338	Z_m	0.2202	Z_a 170.8	Z_w	0.02338	

Step 4

Diameter ratio = A/D0				K	1.045
F	5.484	Φ	7.37	Q_1	-0.05882
Q_{z1}	3.641	Q_{z2}	9.816	U	19.63

Step 5, coefficients

γ(*)	-0.08055	in	ω_S	4.751	in²	ω_S*	-4.681 in²
ω_C	3.461	in²	ω_C*	-2.721	in²	γ_b	0

Results acc. 4.18.8.7 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'	630.2	psi	P_t'	545.5	psi	P_γ	-959.6	psi
P_W	0	psi	P_{rim}	45.07	psi	P_e	-145.1	psi

Step 7

Q_2	-372.5 lbf	Q_3	-0.04676	F_m	0.02338

Strength condition for the tubesheet bending stress, case 7

σ =	14169 psi	< 1.5 · σ_B	= 1.5·	15800 psi	case 1-3
		< S_{PS}	=	47400 psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = 9299 psi

Step 9

F_{tmin}	-0.3403	F_{tmax}	3.906		
x_{min}	2.74	x_{max}	6.587		
$\sigma_{T,1}$	-147.4 psi	$\sigma_{T,2}$	5745 psi		

σ_{tmax} =	5745 psi	≤ σ_T =	16700 psi	for calculation case 1-3
		≤2 · σ_T =	33400 psi	for calculation case 4-7

Tube weld force W_t = 841.1 lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t	0.3367 in	F_t	142.6	C_t	1.297	F_s	166.7

$\lvert\sigma_{tmin}\rvert$ =	-147.4 psi	≤S_{tb} =	8466 psi	(only σ_{tmin} < 0 buckl.)

Buckling stability acc. 4.18.8.4 Step 9 satisfied

Step 10: Axial membrane stress σSm in the shell

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

$\sigma_{Sm} \le$ 0.85· 15800 psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

σ_{Sm} = **1186** psi ≤2· 15800 psi = $2 \cdot \sigma_{allS}$ (4-7)

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

| **1186** psi | < Min(**6749** psi , **43039** psi)

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

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

$\sigma_{Sm} \le$ 0.85· psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

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

| psi | < Min(psi , psi)

ASME external pressure chart A =

Strength condition 4.18.8.4 Step 10 satisfied

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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}| =$ **11024** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}

$\sigma_S =$ | **1186** psi | + | **-9838** psi | ≤ **47400** psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}| =$ **48654** psi ≤1.5 · σ_{allC} or S_{PSc}

$\sigma_C =$ | **5568** psi | + | **43086** psi | ≤ **67336** psi

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

Minimum channel thickness with uniform thickness l_{Cm} **7.155** in

Strength condition 4.18.8.4 Step 11 is satisfied

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

Modulus of elasticity	elastic	Option 3
Shell	**2.64e+7** psi	**2.64e+7** psi
Channel	**2.83e+7** psi	**2.83e+7** psi

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

σ_S = **11024** psi ≤ 47400 psi $= S_{PSs}$

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

σ_C = **48654** psi ≤ 67336 psi $= S_{PSc}$

Geometric conditions:

valid

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

If: Tube sheet thickness= 1.5 in < 1 in

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

4.18.3: The calculation of fixed tubesheets shall be performed with corrosion (corrosion allowance c2>0) and without corrosion (c2=0). Acc. to 4.18.8.3 the shell must eventually be designed for column buckling (in the case of compression).

Equations
Formulas acc. 4.18.8 [in SI-Units]

Allowable primary + secondary shell stress acc. UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2 · Yield strength (b) at operation
47400 psi = 3· 15800 psi or 2· 17446 psi
(b) under the condition: SigZul not in the creep range:
T= 400 °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 38.1\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 38.1\ \text{mm}$$

Step 1

$$D_0 = 2 \cdot (r_0 + d_{aT}) = 2 \cdot (511.3\ \text{mm} + 25.4\ \text{mm}) = 1048\ \text{mm}$$

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

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

Step 2

$$Ks = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = \frac{\pi \cdot t_s \cdot (D_s + t_s) \cdot E_s}{L} = 1467444\ \text{N/mm}$$

$$K_t = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = \frac{\pi \cdot t_T \cdot (d_t - t_T) \cdot E_t}{L} = 2921\ \text{N/mm}$$

Step 3

$$\rho = \frac{l_{t,x}}{h} = \frac{34.92\ \text{mm}}{38.1\ \text{mm}} = 0.9167$$

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

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

$$d_1^* = (d_T - 2 \cdot t_T) \Leftrightarrow d_1^* = (25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm})$$

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) \Leftrightarrow d_2^* = \left(25.4\ \text{mm} - 2 \cdot 1.245\ \text{mm} \cdot \frac{186160\ \text{N/mm}^2}{182023\ \text{N/mm}^2} \cdot \frac{115.1\ \text{N/mm}^2}{108.9\ \text{N/mm}^2} \cdot 0.9167\right)$$

$$\mu^* = \frac{p^* - d^*}{p^*} = \frac{31.75\ \text{mm} - 23.12\ \text{mm}}{31.75\ \text{mm}} = 0.2717$$