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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

In example 4.18.5 step 6 in ASME PTB-4:2021 2022 - ASME Section VIII Division 1 Example Problem Manual, the bolt load W* is calculated as the same for all operating cases.

In our opinion this is wrong.

According to ASME VIII DIV1 Table UHX-8.1 W* is set equal to Wc for the operating cases in configuration B.

Since at page 276, Wc is defined as the flange design bold loads for gasket seating condition to be calculated according to appendix 2.

The calculation of Wc according to appendix 2 shows that it depends on the channel side pressure and this pressure varies according to the concerned operating case.

Wc is depending on Am which is the maximum value of Am1 and Am2, where Am1 is depending on wm1 which is a function of pressure according to appendix 2-5

All deviations above 3% are due to this difference in the bolt load calculation

Deviation of the calculated values

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

Step 1

		LV Soft				ASME		Diff [%]
Eff. tube hole diameter	**d***	2,3E+01	mm	8,91E-01	in	8,9E-01	in	**0,10%**
Effective pitch	**p***	3,2E+01	mm	1,25E+00	in	1,3E+00	in	**0,00%**
Eff. ligament efficiency	**μ***			2,87E-01		2,9E-01		**0,24%**
Parameter	x_s			4,47E-01		4,5E-01		**0,09%**
Parameter	x_t			6,15E-01		6,2E-01		**0,03%**

Step 2

		LV Soft				ASME		Diff [%]
Coefficients for shell	δ_S	2,0E-01	mm^3/N	5,40E-05	in^3/lbf	5,4E-05	in^3/lbf	**0,71%**
	β_S	2,8E-02	1/mm	7,10E-01	1/in	7,1E-01	1/in	**0,00%**
	k_S	9,7E+04	N	2,18E+04	lbf	2,2E+04	lbf	**0,14%**
	λ_S	6,1E+03	Mpa	8,83E+05	psi	8,8E+05	psi	**0,46%**
Shell axial rigidity	K_s	5,7E+05	N/mm	3,24E+06	lbf/in	3,2E+06	lbf/in	**0,12%**
Tube axial rigidity	K_t	6,6E+03	N/mm	3,76E+04	lbf/in	3,8E+04	lbf/in	**0,14%**
Stiffness ratio	K_{st}			1,33E-01		1,3E-01		**0,03%**
Stiffness ratio	**J**			3,50E-03		3,5E-03		**0,13%**

Step 3

		LV Soft	ASME	Diff [%]
Ratio of elasticity tubesheet	**E*/E**	2,63E-01	2,6E-01	**0,00%**
effective Poisson's ratio tubesheet	**ν***	3,64E-01	3,6E-01	**0,02%**

Parameter for table UHX-13.2	X_a	3,96E+00	4,0E+00	**0,05%**
	Z_d	2,47E-02	2,5E-02	**0,16%**
	Z_v	6,43E-02	6,4E-02	**0,12%**
	Z_m	3,72E-01	3,7E-01	**0,09%**
	Z_a	6,53E+00	6,5E+00	**0,26%**
	Z_w	6,43E-02	6,4E-02	**0,12%**

Step 4

		LV Soft	ASME	Diff [%]
Diameter ratio	**K**	1,18E+00	1,2E+00	**0,01%**
Corfficient	**F**	4,87E-01	4,9E-01	**0,32%**
Parameter	**Φ**	6,64E-01	6,7E-01	**0,36%**
	Q_1	-2,27E-02	-2,3E-02	**0,22%**
	Q_{z1}	2,85E+00	2,9E+00	**0,07%**
	Q_{z2}	6,88E+00	6,9E+00	**0,12%**
	U	1,38E+01	1,4E+01	**0,15%**

Step 5

		LV Soft			ASME		Diff [%]
	γ(*)						
	ω_S	mm²		in²		in²	
	ω_S*	mm²		in²		in²	
	ω_C	mm²		in²		in²	
	ω_C*	mm²		in²		in²	
	γ_b		-6,04E-02		-6,0E-02		**0,38%**

Summary table for Step 5 -Design Condition									
Loading Case									
1	P_s	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	Pt	2,8E+00	Mpa	4,00E+02	psi	4,0E+02	psi	**0,00%**
	γ	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**
	W	2,3E+06	N	5,12E+05	lbf	5,1E+05	lbf	**0,03%**
2	P_s	1,0E+00	Mpa	1,50E+02	psi	1,5E+02	psi	**0,00%**
	Pt	0,0E+00	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	1,0E+00	Mpa	1,50E+02	psi	1,5E+02	psi	**0,00%**

	Pt	2,8E+00	Mpa	4,00E+02	psi	4,0E+02	psi	**0,00%**
	γ	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**
	W	2,3E+06	N	5,12E+05	lbf	5,1E+05	lbf	**0,02%**

Summary table for Step 5 -Operation Condition								
Loading Case								
1	**P_s**	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	Pt	2,8E+00	Mpa	4,00E+02	psi	4,0E+02	psi	**0,00%**
	γ	-1,2E+00	mm	-4,73E-02	in	-4,7E-02	in	**0,01%**
	W	2,3E+06	N	5,12E+05	lbf	5,1E+05	lbf	**0,12%**
2	**P_s**	1,0E+00	Mpa	1,50E+02	psi	1,5E+02	psi	**0,00%**
	Pt	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	γ	-1,2E+00	mm	-4,73E-02	in	-4,7E-02	in	**0,01%**
	W	1,4E+06	N	3,09E+05	lbf	5,1E+05	lbf	**39,81%**
3	**P_s**	1,0E+00	Mpa	1,50E+02	psi	1,5E+02	psi	**0,00%**
	Pt	2,8E+00	Mpa	4,00E+02	psi	4,0E+02	psi	**0,00%**
	γ	-1,2E+00	mm	-4,73E-02	in	-4,7E-02	in	**0,01%**
	W	2,3E+06	N	5,13E+05	lbf	5,1E+05	lbf	**0,03%**
4	**P_s**	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	Pt	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	γ	-1,2E+00	mm	-4,73E-02	in	-4,7E-02	in	**0,01%**
	W	1,6E+06	N	3,67E+05	lbf	5,1E+05	lbf	**28,52%**

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'	5,9E+03	Mpa	8,61E+05	psi	8,6E+05	psi	**0,13%**
	$P_γ$		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	1,6E+00	Mpa	2,31E+02	psi	2,3E+02	psi	**0,27%**
	P_{rim}	1,2E+00	Mpa	1,81E+02	psi	1,8E+02	psi	**0,61%**
	P_e	-2,8E+00	Mpa	-3,99E+02	psi	-4,0E+02	psi	**0,01%**
2	**P_s'**	-3,2E+02	Mpa	-4,62E+04	psi	-4,6E+04	psi	**0,49%**
	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}	1,3E-01	Mpa	1,87E+01	psi	1,9E+01	psi	**0,09%**
	P_e	-1,5E-01	Mpa	-2,14E+01	psi	-2,2E+01	psi	**0,38%**
3	P_s'	-3,2E+02	Mpa	-4,62E+04	psi	-4,6E+04	psi	**0,49%**
	P_t'	5,9E+03	Mpa	8,61E+05	psi	8,6E+05	psi	**0,13%**
	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	1,6E+00	Mpa	2,31E+02	psi	2,3E+02	psi	**0,21%**
	P_{rim}	1,4E+00	Mpa	1,99E+02	psi	2,0E+02	psi	**0,58%**
	P_e	-2,9E+00	Mpa	-4,21E+02	psi	-4,2E+02	psi	**0,01%**

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'	5,9E+03	Mpa	8,61E+05	psi	8,6E+05	psi	**0,13%**
	P_γ	-8,6E+00	Mpa	-1,25E+03	psi	-1,3E+03	psi	**0,16%**
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	1,6E+00	Mpa	2,31E+02	psi	2,3E+02	psi	**0,13%**
	P_{rim}	1,2E+00	Mpa	1,81E+02	psi	1,8E+02	psi	**0,61%**
	P_e	-2,8E+00	Mpa	-4,00E+02	psi	-4,0E+02	psi	**0,00%**
2	P_s'	-3,2E+02	Mpa	-4,62E+04	psi	-4,6E+04	psi	**0,50%**
	P_t'	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_γ	-8,6E+00	Mpa	-1,25E+03	psi	-1,3E+03	psi	**0,16%**
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	1,1E+00	Mpa	1,65E+02	psi	2,3E+02	psi	**28,37 %**
	P_{rim}	1,3E-01	Mpa	1,87E+01	psi	1,9E+01	psi	**0,10%**
	P_e	-1,5E-01	Mpa	-2,19E+01	psi	-2,2E+01	psi	**0,22%**
3	P_s'	-3,2E+02	Mpa	-4,62E+04	psi	-4,6E+04	psi	**0,50%**
	P_t'	5,9E+03	Mpa	8,61E+05	psi	8,6E+05	psi	**0,13%**
	P_γ	-8,6E+00	Mpa	-1,25E+03	psi	-1,3E+03	psi	**0,16%**

	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	1,6E+00	Mpa	2,31E+02	psi	2,3E+02	psi	**0,56%**
	P_{rim}	1,4E+00	Mpa	1,99E+02	psi	2,0E+02	psi	**0,56%**
	P_e	-2,9E+00	Mpa	-4,21E+02	psi	-4,2E+02	psi	**0,02%**
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	-8,6E+00	Mpa	-1,25E+03	psi	-1,3E+03	psi	**0,16%**
	P_ω	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_W	1,1E+00	Mpa	1,65E+02	psi	2,3E+02	psi	**28,37 %**
	P_{rim}	0,0E+00	Mpa	0,00E+00	psi	0,0E+00	psi	**0,00%**
	P_e	-3,5E-03	Mpa	-5,04E-01	psi	-4,7E-01	psi	**6,32%**

Summary table for Step 7 -Design Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	Q_2	-3,1E+04	N	-7,05E+03	lbf	-7,0E+03	psi	**0,10%**
	Q_3			9,76E-02		9,8E-02	psi	**0,00%**
	F_m			9,76E-02		9,8E-02	psi	**0,06%**
	hg'	0,0E+00	mm	0,00E+00	in	0,0E+00	psi	**0,00%**
	h	7,8E+01	mm					
	h-hg'	7,8E+01	mm	3,06E+00	in	3,1E+00	psi	**0,02%**
	$\lvert\sigma_{elastic}\rvert$	1,8E+02	Mpa	2,55E+04	psi	2,6E+04	psi	**0,10%**
	1,5S	1,2E+02	Mpa	2,69E+04	psi	2,7E+04	psi	**0,82%**
2	Q_2	-1,4E+03	N	-3,20E+02	lbf	-3,2E+02	psi	**0,17%**
	Q_3			7,90E-02		7,9E-02	psi	**0,52%**
	F_m			9,02E-02		9,0E-02	psi	**0,11%**
	hg'	0,0E+00	mm	0,00E+00	in	0,0E+00	psi	**0,00%**
	h	7,8E+01	mm					
	h-hg'	7,8E+01	mm	3,06E+00	in	3,1E+00	psi	**0,02%**
	$\lvert\sigma_{elastic}\rvert$	8,7E+00	Mpa	1,27E+03	psi	1,3E+03	psi	**0,25%**
	1,5S	1,2E+02	Mpa	2,69E+04	psi	2,7E+04	psi	**0,81%**
3	Q_2	-3,3E+04	N	-7,36E+03	lbf	-7,4E+03	psi	**0,03%**
	Q_3			9,66E-02		9,7E-02	psi	**0,02%**

	F_m			9,72E-02		9,7E-02	psi	**0,06%**
	hg'	0,0E+00	mm	0,00E+00	in	0,0E+00	psi	**0,00%**
	h	7,8E+01	mm					
	h-hg'	7,8E+01	mm	3,06E+00	in	3,1E+00	psi	**0,02%**
	$\lvert\sigma_{elastic}\rvert$	1,8E+02	Mpa	2,68E+04	psi	2,7E+04	psi	**0,12%**
	1,5S	1,2E+02	Mpa	2,69E+04	psi	2,7E+04	psi	**0,81%**

Summary table for Step 7 -Operation Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	Q_2	-3,1E+04	N	-7,05E+03	lbf	- 7,0E+03	psi	**0,06%**
	Q_3			9,74E-02		9,7E-02		**0,07%**
	F_m			9,74E-02		9,7E-02		**0,03%**
	hg'	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**
	h	7,8E+01	mm					
	h-hg'	7,8E+01	mm	3,06E+00	in	3,1E+00	in	**0,02%**
	$\lvert\sigma_{elastic}\rvert$	1,8E+02	Mpa	2,55E+04	psi	2,6E+04	psi	**0,14%**
	S_{ps}	3,8E+02	Mpa	5,45E+04	psi	5,4E+04	psi	**0,21%**
2	Q_2	-1,4E+04	N	-3,15E+03	lbf	- 4,3E+03	psi	**26,08 %**
	Q_3			9,55E-01		1,3E+00		**26,55 %**
	F_m			5,00E-01		6,7E-01		**25,41 %**
	hg'	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**
	h	7,8E+01	mm					
	h-hg'	7,8E+01	mm	3,06E+00	in	3,1E+00	in	**0,02%**
	$\lvert\sigma_{elastic}\rvert$	5,0E+01	Mpa	7,19E+03	psi	9,7E+03	psi	**25,59 %**
	S_{ps}	3,8E+02	Mpa	5,45E+04	psi	5,4E+04	psi	**0,21%**
3	Q_2	-3,3E+04	N	-7,37E+03	lbf	- 7,4E+03	psi	**0,06%**
	Q_3			9,65E-02		9,7E-02		**0,03%**
	F_m			9,71E-02		9,7E-02		**0,04%**
	hg'	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**
	h	7,8E+01	mm					
	h-hg'	7,8E+01	mm	3,06E+00	in	3,1E+00	in	**0,02%**
	$\lvert\sigma_{elastic}\rvert$	1,8E+02	Mpa	2,68E+04	psi	2,7E+04	psi	**0,07%**
	S_{ps}	3,8E+02	Mpa	5,45E+04	psi	5,4E+04	psi	**0,21%**
4	Q_2	-1,3E+04	N	-2,83E+03	lbf	-	psi	**28,20**

						3,9E+03		%
	Q$_3$			3,82E+01		5,7E+01		**32,54 %**
	F$_m$			1,92E+01		2,8E+01		**32,51 %**
	hg'	0,0E+00	mm	0,00E+00	in	0,0E+00	in	**0,00%**
	h	7,8E+01	mm					
	h-hg'	7,8E+01	mm	3,06E+00	in	3,1E+00	in	**0,02%**
	|σ$_{elastic}$|	4,6E+01	Mpa	6,62E+03	psi	8,8E+03	psi	**25,09 %**
	S$_{ps}$	3,8E+02	Mpa	5,45E+04	psi	5,4E+04	psi	**0,21%**

Summary table for Step 8 -Design Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	**0,8S**	9,9E+01	Mpa	1,44E+04	psi	1,4E+04	psi	**0,82%**
2	**0,8S**	9,9E+01	Mpa	1,44E+04	psi	1,4E+04	psi	**0,82%**
3	**0,8S**	9,9E+01	Mpa	1,44E+04	psi	1,4E+04	psi psi	**0,82%**

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

Summary table for Step 9 -Design Condition

				LV Soft		ASME		Diff [%]
Loading Case								
1	$F_{t,min}$			-1,08E+00		- 1,1E+00		**0,07%**
	$\sigma_{t,1}$	-2,8E+01	Mpa	-4,03E+03	psi	- 4,0E+03	psi	**0,13%**
	$F_{t,max}$			3,81E+00		3,8E+00		**0,05%**
	$\sigma_{t,2}$	5,2E+01	Mpa	7,57E+03	psi	7,6E+03	psi	**0,01%**
2	$F_{t,min}$			-1,01E+00		- 1,0E+00		**0,21%**
	$\sigma_{t,1}$	1,9E+00	Mpa	2,69E+02	psi	2,7E+02	psi	**0,21%**
	$F_{t,max}$			3,66E+00		3,7E+00		**0,03%**
	$\sigma_{t,2}$	6,0E+00	Mpa	8,64E+02	psi	8,6E+02	psi	**0,09%**
3	$F_{t,min}$			-1,08E+00		- 1,1E+00		**0,11%**
	$\sigma_{t,1}$	-2,6E+01	Mpa	-3,76E+03	psi	- 3,8E+03	psi	**0,12%**
	$F_{t,max}$			3,80E+00		3,8E+00		**0,08%**
	$\sigma_{t,2}$	5,8E+01	Mpa	8,43E+03	psi	8,4E+03	psi	**0,01%**

Summary table for Step 9 -Operation Condition								
				LV Soft		ASME		Diff [%]
Loading Case								
1	$F_{t,min}$			-1,08E+00		- 1,1E+00		**0,01%**
	$\sigma_{t,1}$	-2,8E+01	Mpa	-4,03E+03	psi	- 4,2E+03	psi	**4,18%**
	$F_{t,max}$			3,80E+00		3,8E+00		**0,06%**
	$\sigma_{t,2}$	5,2E+01	Mpa	7,58E+03	psi	7,6E+03	psi	**0,03%**
2	$F_{t,min}$			-4,25E+00		- 5,5E+00		**22,93 %**
	$\sigma_{t,1}$	-1,1E+00	Mpa	-1,56E+02	psi	- 3,2E+02	psi	**51,72 %**
	$F_{t,max}$			1,06E+01		1,3E+01		**20,48 %**
	$\sigma_{t,2}$	1,2E+01	Mpa	1,78E+03	psi	2,1E+03	psi	**16,74 %**
3	$F_{t,min}$			-1,08E+00		- 1,1E+00		**0,06%**
	$\sigma_{t,1}$	-2,6E+01	Mpa	-3,76E+03	psi	- 3,8E+03	psi	**0,10%**
	$F_{t,max}$			3,80E+00		3,8E+00		**0,07%**

	$\sigma_{t,2}$	5,8E+01	Mpa	8,44E+03	psi	8,4E+03	psi	**0,03%**
4	$F_{t,min}$			-1,44E+02		-2,1E+02		**32,43 %**
	$\sigma_{t,1}$	-3,0E+00	Mpa	-4,32E+02	psi	-6,0E+02	psi	**28,11 %**
	$F_{t,max}$			3,06E+02		4,5E+02		**32,38 %**
	$\sigma_{t,2}$	6,3E+00	Mpa	9,15E+02	psi	1,3E+03	psi	**28,04 %**

Summary table for Step 9 -Design Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	$\sigma_{t,max}$	5,2E+01	Mpa	7,57E+03	psi	7,6E+03	psi	**0,01%**
	$\lvert\sigma_{t,min}\rvert$	2,8E+01	Mpa	4,03E+03	psi	4,0E+03	psi	**0,13%**
	Fs			1,35E+00		1,3E+00		**0,07%**
	S_{tb}	3,9E+01	Mpa	5,68E+03	psi	5,7E+03	psi	**0,19%**
2	$\sigma_{t,max}$	6,0E+00	Mpa	8,64E+02	psi	8,6E+02	psi	**0,09%**
	$\lvert\sigma_{t,min}\rvert$		Mpa		psi		psi	
	Fs							
	S_{tb}		Mpa		psi		psi	
3	$\sigma_{t,max}$	5,8E+01	Mpa	8,43E+03	psi	8,4E+03	psi	**0,01%**
	$\lvert\sigma_{t,min}\rvert$	2,6E+01	Mpa	3,76E+03	psi	3,8E+03	psi	**0,12%**
	Fs			1,35E+00		1,4E+00		**0,07%**
	S_{tb}	3,9E+01	Mpa	5,67E+03	psi	5,7E+03	psi	**0,19%**

Summary table for Step 9 -Operation Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	$\sigma_{t,max}$	5,2E+01	Mpa	7,58E+03	psi	7,6E+03	psi	**0,03%**

	$\lvert\sigma_{t,min}\rvert$	2,8E+01	Mpa	4,03E+03	psi	4,2E+03	psi	**4,18%**
	Fs			1,35E+00		1,3E+00		**0,11%**
	S_{tb}	3,9E+01	Mpa	5,69E+03	psi	5,7E+03	psi	**0,10%**
2	$\sigma_{t,max}$	1,2E+01	Mpa	1,78E+03	psi	2,1E+03	psi	**16,74 %**
	$\lvert\sigma_{t,min}\rvert$	1,1E+00	Mpa	1,55E+02	psi	3,2E+02	psi	**51,74 %**
	Fs			1,25E+00		1,3E+00		**0,00%**
	S_{tb}	4,2E+01	Mpa	6,12E+03	psi	6,1E+03	psi	**0,10%**
3	$\sigma_{t,max}$	5,8E+01	Mpa	8,44E+03	psi	8,4E+03	psi	**0,03%**
	$\lvert\sigma_{t,min}\rvert$	2,6E+01	Mpa	3,76E+03	psi	3,8E+03	psi	**0,10%**
	Fs			1,35E+00		1,4E+00		**0,07%**
	S_{tb}	3,9E+01	Mpa	5,66E+03	psi	5,7E+03	psi	**0,20%**
4	$\sigma_{t,max}$	6,3E+00	Mpa	9,15E+02	psi	1,3E+03	psi	**28,06 %**
	$\lvert\sigma_{t,min}\rvert$	3,0E+00	Mpa	4,32E+02	psi	6,0E+02	psi	**28,11 %**
	Fs			1,25E+00		1,3E+00		**0,00%**
	S_{tb}	4,2E+01	Mpa	6,12E+03	psi	6,1E+03	psi	**0,10%**

Summary table for Step 10 und 11 -Design Condition								
		LV Soft				**ASME**		**Diff [%]**
Loading Case								
1	$\sigma_{s,m}$	1,8E-01	Mpa	2,61E+01	psi	2,6E+01	psi	**0,06%**
	$\sigma_{s,b}$	-2,9E+02	Mpa	-4,24E+04	psi	- 4,2E+04	psi	**0,08%**
	σ_s	2,9E+02	Mpa	4,24E+04	psi	4,2E+04	psi	**0,09%**
	$1.5S_s$	1,9E+02	Mpa	2,69E+04	psi	2,7E+04	psi	**0,82%**
2	$\sigma_{s,m}$	-5,3E+00	Mpa	-7,64E+02	psi	- 7,6E+02	psi	**0,14%**
	$\sigma_{s,b}$	1,3E+02	Mpa	1,92E+04	psi	1,9E+04	psi	**0,02%**
	σ_s	1,4E+02	Mpa	2,00E+04	psi	2,0E+04	psi	**0,01%**
	$1.5S_s$	1,9E+02	Mpa	2,69E+04	psi	2,7E+04	psi	**0,82%**
3	$\sigma_{s,m}$	-5,1E+00	Mpa	-7,38E+02	psi	-	psi	**0,15%**

						7,4E+02		
	$\sigma_{s,b}$	-1,6E+02	Mpa	-2,32E+04	psi	- 2,3E+04	psi	**0,28%**
	σ_s	1,6E+02	Mpa	2,39E+04	psi	2,4E+04	psi	**0,29%**
	$1.5S_s$	1,9E+02	Mpa	2,69E+04	psi	2,7E+04	psi	**0,82%**

Summary table for Step 10 und 11 -Operation Condition								
		LV Soft				ASME		Diff [%]
Loading Case								
1	$\sigma_{s,m}$	4,3E-04	Mpa	6,22E-02	psi	5,9E-02	psi	**6,15%**
	$\sigma_{s,b}$	-2,9E+02	Mpa	-4,24E+04	psi	- 4,2E+04	psi	**0,09%**
	σ_s	2,9E+02	Mpa	4,24E+04	psi	4,2E+04	psi	**0,09%**
	$S_{pS,s}$	3,8E+02	Mpa	5,45E+04	psi	5,4E+04	psi	**0,21%**
2	$\sigma_{s,m}$	-5,4E+00	Mpa	-7,86E+02	psi	- 7,9E+02	psi	**0,02%**
	$\sigma_{s,b}$	8,0E+01	Mpa	1,16E+04	psi	8,6E+03	psi	**34,94 %**
	σ_s	8,6E+01	Mpa	1,24E+04	psi	9,4E+03	psi	**32,03 %**
	$S_{pS,s}$	3,8E+02	Mpa	5,45E+04	psi	5,4E+04	psi	**0,21%**
3	$\sigma_{s,m}$	-5,3E+00	Mpa	-7,64E+02	psi	- 7,6E+02	psi	**0,15%**
	$\sigma_{s,b}$	-1,6E+02	Mpa	-2,32E+04	psi	- 2,3E+04	psi	**0,37%**
	σ_s	1,7E+02	Mpa	2,41E+04	psi	2,4E+04	psi	**0,36%**
	$S_{pS,s}$	3,8E+02	Mpa	5,45E+04	psi	5,4E+04	psi	**0,21%**
4	$\sigma_{s,m}$	-1,6E-01	Mpa	-2,26E+01	psi	- 2,1E+01	psi	**6,35%**
	$\sigma_{s,b}$	-5,2E+01	Mpa	-7,59E+03	psi	- 1,1E+04	psi	**28,23 %**
	σ_s	5,3E+01	Mpa	7,62E+03	psi	1,1E+04	psi	**28,15 %**
	$S_{pS,s}$	3,8E+02	Mpa	5,45E+04	psi	5,4E+04	psi	**0,21%**

A188-1 - Fixed Tubesheets - ASME BPVC VIII-2, 2025

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

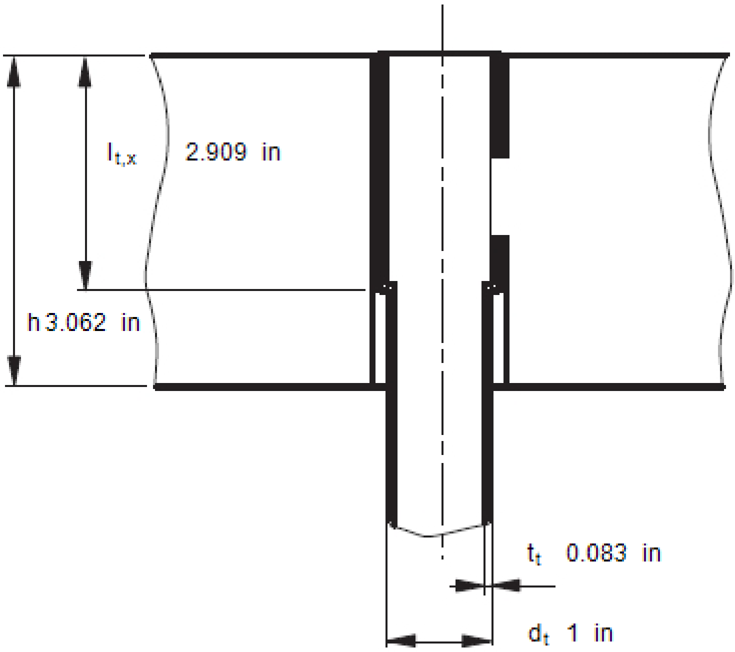
Configuration of the tubesheet (a, b, c, d)	Type	*b*	
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	
Internal operating pressure shell side	P_s	*150*	psi
Internal operating pressure tube side	P_t	*400*	psi
Minimum shell-side operating pressure	$P_{s,min}$	0	psi
Minimum tube-side operating pressure	$P_{t, min}$	0	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=Ps,min) without differential thermal expansion			

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

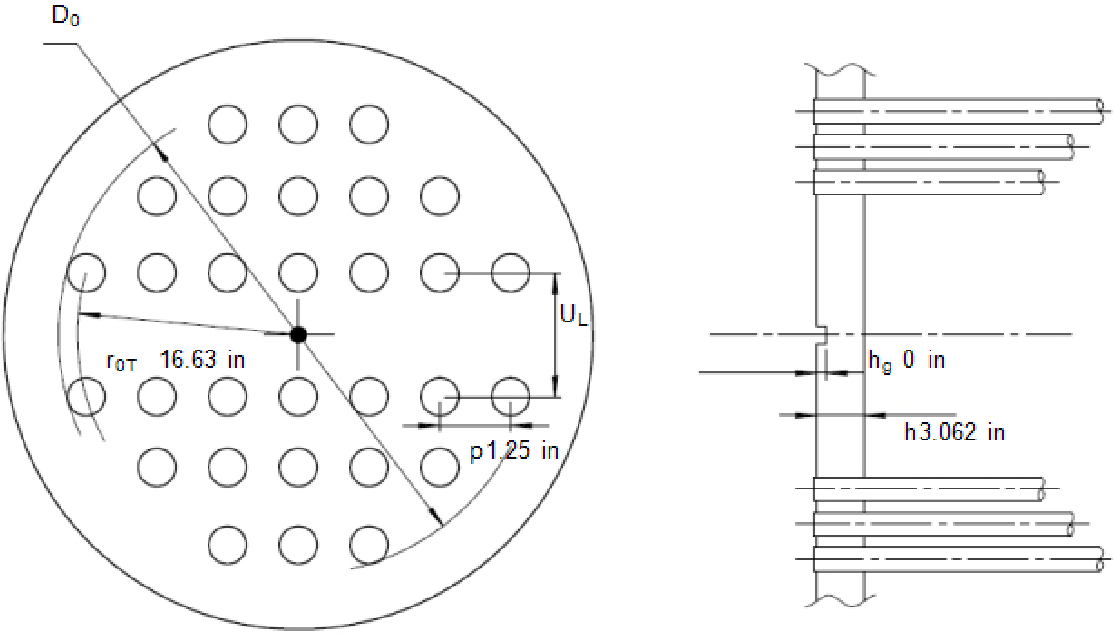
Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	0	in	0	in	0	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
Modulus of elasticity		*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion		*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength		*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature		1000	°F	1000	°F	1000	°F
Allow. stress		***17952***	psi	***10430***	psi	***17952***	psi
Prim.+sec. str.		***54515***	psi			***54515***	psi
Properties for testing at 20°C							
Strength *)		33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

Additional specifications for the geometry and loading
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*
Tube pattern	(1=Triangle, 2=Square)		*1*
Number of tubes		N_t	*649*



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.95**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*16.63*	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		in²
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	*161.9*	in
Unsupported tube span for buckling	l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	1	
Equivalent free buckling length k·l	l_t	***59***	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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'	*6.389*	1E-6/°F
Channel at T'_c	α'_c		1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*6.389*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F
Flange (Type bcd):			
Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512301**	lbf
Total req. bolt area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.235**	in
Maximum bolt force for all calculation cases	W_{max}			*0*	lbf

Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**512774**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2868**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6154**	
Type abc: Coefficients for shell pressure	δ_S	**0.1982**	mm^3/N

β_S **8.522** 1/ft k_S **21840** lbf λ_S **883439** psi

Step 2

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

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2	E*	**6722364**	psi
Ratio of elasticity tubesheet		E*/E	**0.2639**	
effective Poisson's ratio tubesheet		ν*	**0.3634**	
Parameter for table 4.18.3		X_a	**3.961**	

Z_d **0.02465** Z_v **0.06434** Z_m **0.3718** Z_a **6.53** Z_w **0.06434**

Step 4

Diameter ratio = A/D0   K **1.182**

F	**0.4873**	Φ	**0.6643**	Q_1	**-0.02269**
Q_{z1}	**2.854**	Q_{z2}	**6.88**	U	**13.76**

Step 5, coefficients

γ(*)	**0** in	ω_S	**2.687** in²	ω_S*	**-2.656** in²
ω_C	**0** in²	ω_C*	**9.639** in²	γ_b	**-0.06045**

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'	**860900** psi	P_γ	**0** psi
P_W	**231.3** psi	P_{rim}	**180.8** psi	P_e	**-399.4** psi

Step 7

Q_2 **-7048** lbf Q_3 **0.09758** F_m **0.09756**

Strength condition for the tubesheet bending stress, case 1

σ = **25514** psi   < 1.5 · σ_B = 1.5· ***17952*** psi   case 1-3
< S_{PS} = ***54515*** psi   case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi   ≤ MIN[0.8σ_B ; 0.533 S_y] = **14362** psi

Step 9

F_{tmin} -1.082 | F_{tmax} 3.806
x_{min} 0 | x_{max} 3.961
$\sigma_{T,1}$ -4029 psi | $\sigma_{T,2}$ 7569 psi

σ_{tmax} = 7569 psi $\leq \sigma_T$ = *10430* psi for calculation case 1-3
$\leq 2 \cdot \sigma_T$ = 20860 psi for calculation case 4-7

Tube weld force W_t = 1810 lbf $\leq W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t 0.3255 in F_t 181.2 C_t 1.347 F_s 164.2

$|\sigma_{tmin}|$ = | -4029 psi | $\leq S_{tb}$ = 5682 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 = *0.1875* in : (calculation case)
$\sigma_{Sm} \leq$ *1*· *17952* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

For σSm < 0: | σ_{Sm} | < Min(B, A·E/2) acc. UG-23(b)
26.09 psi < Min(8493 psi , 16994 psi)
ASME external pressure chart CS-2 A = 0.001334

Region of increased thickness t_{1s} = in : (calculation case)
$\sigma_{Sm} \leq$ *1*· psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

For σSm < 0: | σ_{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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = 42433 psi $\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}
σ_S = | 26.09 psi | + | -42407 psi | ≤ 26929 psi

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

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

Strength condition 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	**2.547e+7** psi	**2.547e+7** psi
Channel	psi	psi

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

σ_S = **42433** psi ≤ ***54515*** psi $=S_{PSs}$

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

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

Geometric conditions:

valid

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

If: Tube sheet thickness= *3.062* 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
54515 psi = 3· ***17952*** psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

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

Step 1

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

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

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

Step 2

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

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

Step 3

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

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

$$d^* = Max\begin{cases}d_1^*\\ d_2^*\end{cases}$$

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

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

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

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

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

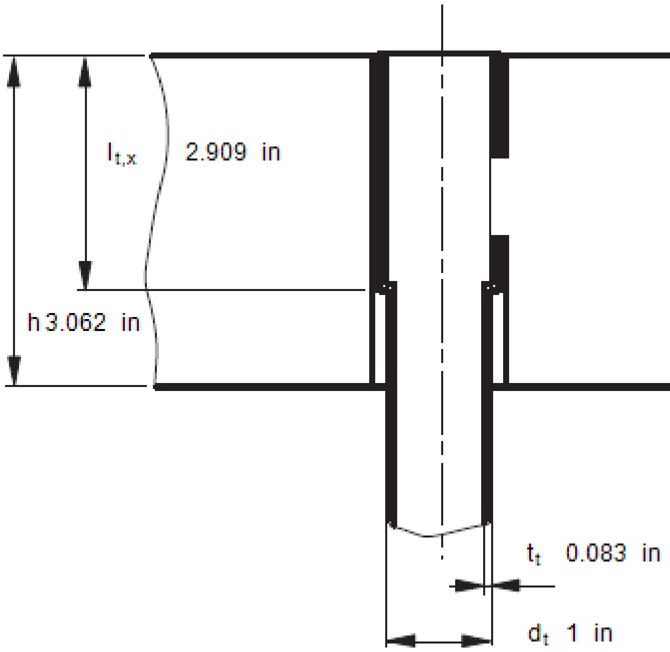
Configuration of the tubesheet (a, b, c, d)		Type	*b*	
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	
Internal operating pressure shell side		P_s	*150*	psi
Internal operating pressure tube side		P_t	*400*	psi
Minimum shell-side operating pressure		$P_{s,min}$	0	psi
Minimum tube-side operating pressure		$P_{t,\ min}$	0	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=Pt,min) without differential thermal expansion				
Tubesheet material	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

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

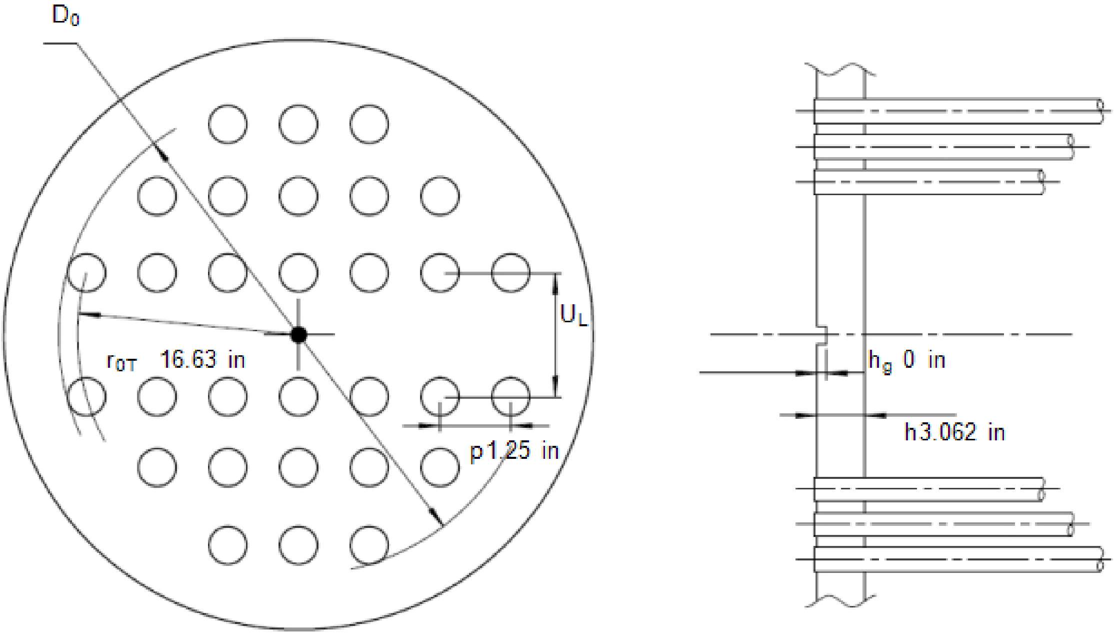
Properties for the selected load case temperature						
Strength operat.	17952	psi	10430	psi	17952	psi
Safety operation	1		1		1	
Modulus of elasticity	*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion	*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength	*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature	1000	°F	1000	°F	1000	°F
Allow. stress	*17952*	psi	*10430*	psi	*17952*	psi
Prim.+sec. str.	*54515*	psi			*54515*	psi
Properties for testing at 20°C						
Strength *)	33939	psi	23496	psi	33939	psi
Safety factor	1		1		1	
Yield strength	37710	psi	26107	psi	37710	psi
Tensile strength	70343	psi	47137	psi	70343	psi

Additional specifications for the geometry and loading
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*
Tube pattern	(1=Triangle, 2=Square)		*1*
Number of tubes		N_t	*649*



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.95**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*16.63*	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		in²
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	*161.9*	in
Unsupported tube span for buckling	l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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'	*6.389*	1E-6/°F
Channel at T'_c	α'_c		1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*6.389*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F
Flange (Type bcd):			
Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_S	24946	psi
Strength for test	K_{sp}	24946	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**8.82**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**0.9888**	in

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

Results acc. 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	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2868**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1-N_t \cdot (0.5 \cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1-N_t \cdot (0.5 \cdot d_i TUBE/a_0)^2$	x_t	**0.6154**	
Type abc: Coefficients for shell pressure	δ_S	**0.1982**	mm^3/N

β_S **8.522** 1/ft k_S **21840** lbf λ_S **883439** psi

Step 2

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

Step 3

Effective modulus of el. tubesheet Fig. 4.18.1-2	E*	**6722554**	psi
Ratio of elasticity tubesheet	E*/E	**0.2639**	
effective Poisson's ratio tubesheet	ν*	**0.3634**	
Parameter for table 4.18.3	X_a	**3.961**	

Z_d **0.02465** Z_v **0.06434** Z_m **0.3718** Z_a **6.529** Z_w **0.06434**

Step 4

Diameter ratio = A/D0 K **1.182**

F	**0.4872**	Φ	**0.6643**	Q_1	**-0.02269**
Q_{z1}	**2.854**	Q_{z2}	**6.88**	U	**13.76**

Step 5, coefficients

γ(*)	**0** in	ω_S	**2.687** in²	ω_S*	**-2.656** in²
ω_C	**0** in²	ω_C*	**9.639** in²	γ_b	**-0.06045**

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'	**-46159** psi	P_t'	**0** psi	P_γ	**0** psi
P_W	**0** psi	P_{rim}	**18.68** psi	P_e	**-21.42** psi

Step 7

Q_2 **-319.5** lbf Q_3 **0.079** F_m **0.09027**

Strength condition for the tubesheet bending stress, case 2

σ = **1266** psi < 1.5 · σ_B = 1.5· *17952* psi case 1-3
< S_{PS} = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = **14362** psi

Step 9

F_{tmin}	-1.013	F_{tmax}	3.659
x_{min}	0	x_{max}	3.961
$\sigma_{T,1}$	269.5 psi	$\sigma_{T,2}$	863.9 psi

σ_{tmax} = 863.9 psi $\leq \sigma_T$ = *10430* psi for calculation case 1-3
$\leq 2 \cdot \sigma_T$ = 20860 psi for calculation case 4-7

Tube weld force W_t = 206.6 lbf $\leq W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t 0.3255 in F_t 181.2 C_t 1.42 F_s 164.2

$|\sigma_{tmin}|$ = | 269.5 psi | $\leq S_{tb}$ = 5388 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 = *0.1875* in : (calculation case)
$\sigma_{Sm} \leq$ *1*· *17952* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

For σSm < 0: | σ_{Sm} | < Min(B, A·E/2) acc. UG-23(b)
-763.7 psi < Min(8493 psi , 16994 psi)
ASME external pressure chart CS-2 A = 0.001334
Region of increased thickness t_{1s} = in : (calculation case)
$\sigma_{Sm} \leq$ *1*· psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

For σSm < 0: | σ_{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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = 20006 psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}
σ_S = | -763.7 psi | + | 19243 psi | ≤ 26929 psi

$\sigma_C = |\sigma_{Cm}| + |\sigma_{Cb}|$ = 0 psi ≤1.5 · σ_{allC} or S_{PSc}
σ_C = | 0 psi | + | 0 psi | ≤ 0 psi

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

Strength condition 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	**2.547e+7** psi	**2.547e+7** psi
Channel	psi	psi

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

σ_S = **20006** psi ≤ *54515* psi =S_{PSs}

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

σ_C = **0** psi ≤ *0* psi =S_{PSc}

Geometric conditions:

valid

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

If: Tube sheet thickness= *3.062* 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·σ_{all} (a) or 2 · Yield strength (b) at operation
54515 psi = 3· *17952* psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

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

Step 1

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

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

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

Step 2

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

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

Step 3

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

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

$$d^* = Max\begin{cases}d_1^*\\ d_2^*\end{cases}$$

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

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

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

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

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

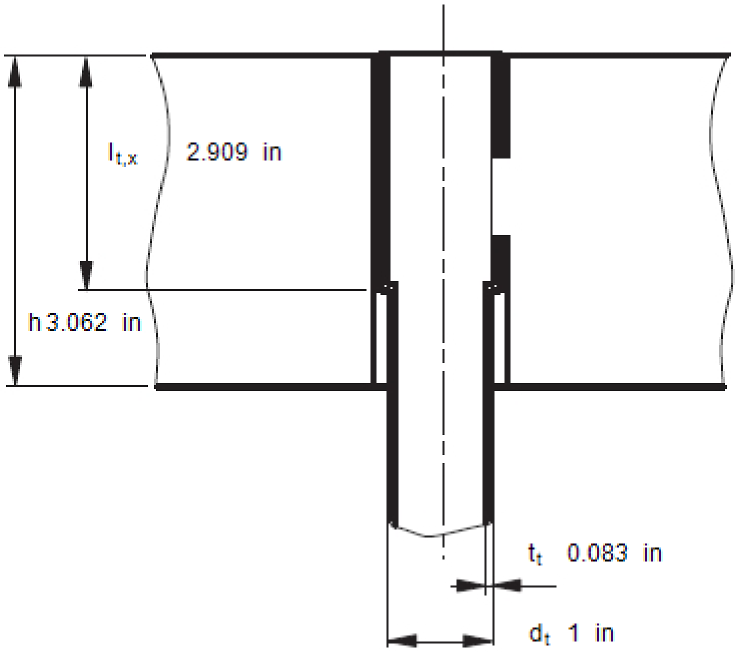
Configuration of the tubesheet (a, b, c, d)	Type	*b*	
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	
Internal operating pressure shell side	P_s	*150*	psi
Internal operating pressure tube side	P_t	*400*	psi
Minimum shell-side operating pressure	$P_{s,min}$	0	psi
Minimum tube-side operating pressure	$P_{t, min}$	0	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	*K02700-SA-516-70-Class:-Size:*
Tube material	*K01807-SA-214--Class:-Size:*
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*

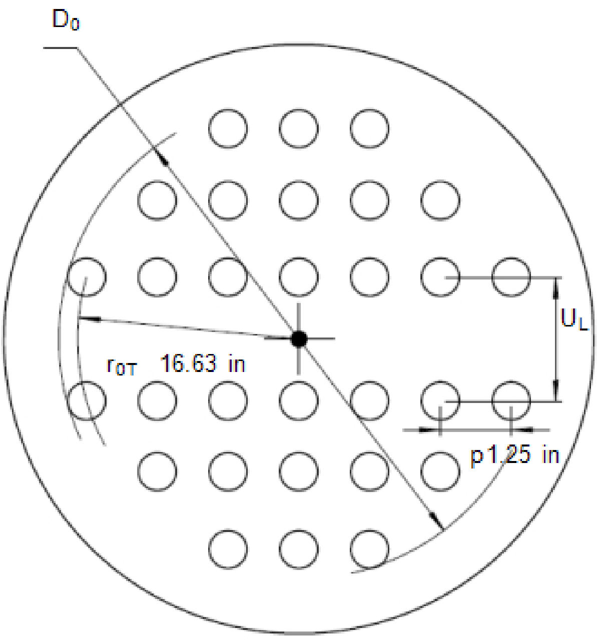
Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	0	in	0	in	0	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
Modulus of elasticity		*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion		*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength		*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature		1000	°F	1000	°F	1000	°F
Allow. stress		*17952*	psi	*10430*	psi	*17952*	psi
Prim.+sec. str.		*54515*	psi			*54515*	psi
Properties for testing at 20°C							
Strength *)		33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

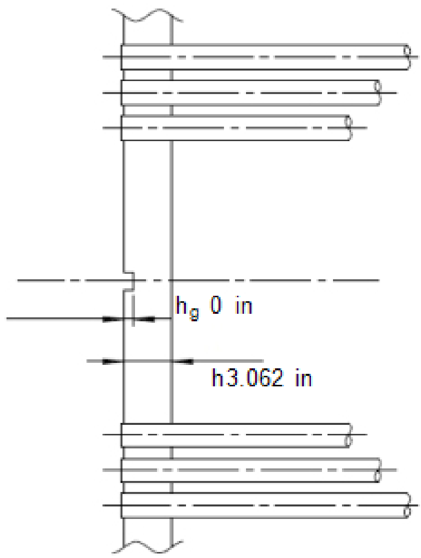
Additional specifications for the geometry and loading
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*
Tube pattern	(1=Triangle, 2=Square)		*1*
Number of tubes		N_t	*649*



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.95**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*16.63*	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		in²
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	*161.9*	in
Unsupported tube span for buckling	l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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'	*6.389*	1E-6/°F
Channel at T'_c	α'_c		1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*6.389*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F
Flange (Type bcd):			
Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512301**	lbf
Total req. bolt area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.235**	in

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

Results acc. 4.18.8.4

Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**512774**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	0.2	
Effective tube hole diameter	d*	0.8915	in
Effective pitch	p*	1.25	in
Effective ligament efficiency for shear	μ*	0.2868	
Effective depth of pass partition groove	h_g'	0	in
Equivalent radius of outer tube limit circle	a_0	17.13	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	18.4	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	17.38	in
Ratio = ac/a0	ρ_C	1.074	
Ratio = as/a0	ρ_S	1.014	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	0.4471	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	0.6154	
Type abc: Coefficients for shell pressure	δ_S	0.1982	mm^3/N

β_S	8.522	1/ft	k_S	21840	lbf	λ_S	883439	psi

Step 2

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

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2	E*	6722554	psi
Ratio of elasticity tubesheet		E*/E	0.2639	
effective Poisson's ratio tubesheet		ν*	0.3634	
Parameter for table 4.18.3		X_a	3.961	

Z_d	0.02465	Z_v	0.06434	Z_m	0.3718	Z_a	6.529	Z_w	0.06434

Step 4

Diameter ratio = A/D0				K	1.182
F	0.4872	Φ	0.6643	Q_1	-0.02269
Q_{z1}	2.854	Q_{z2}	6.88	U	13.76

Step 5, coefficients

γ(*)	0	in	ω_S	2.687	in²	ω_S*	-2.656	in²
ω_C	0	in²	ω_C*	9.639	in²	γ_b	-0.06045	

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'	-46159	psi	P_t'	860900	psi	P_γ	0	psi
P_W	231.3	psi	P_{rim}	199.5	psi	P_e	-420.8	psi

Step 7

Q_2	-7368	lbf	Q_3	0.09663	F_m	0.09719

Strength condition for the tubesheet bending stress, case 3

σ	=	26779	psi	$< 1.5\cdot\sigma_B$	= 1.5·	*17952*	psi	case 1-3
				$< S_{PS}$	=	*54515*	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

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

Step 9

F_{tmin}	**-1.078**	F_{tmax}	**3.799**
x_{min}	**0**	x_{max}	**3.961**
$\sigma_{T,1}$	**-3760** psi	$\sigma_{T,2}$	**8433** psi

σ_{tmax} =	**8433** psi	$\leq \sigma_T$	=	*10430* psi	for calculation case 1-3
		$\leq 2 \cdot \sigma_T$	=	**20860** psi	for calculation case 4-7

Tube weld force W_t = **2016** lbf $\leq W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

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

$|\sigma_{tmin}|$ = | **-3760** psi | $\leq S_{tb}$ = **5667** 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 = *0.1875* in : (calculation case)

$\sigma_{Sm} \leq$		*1*·	*17952* psi	= $E_{sw} \cdot \sigma_{allS}$	(1-3)
σ_{Sm} =	**-737.6** psi	≤2·	*17952* psi	= $2 \cdot \sigma_{allS}$	(4-7)

For σSm < 0: | σ_{Sm} | < Min(B, A·E/2) acc. UG-23(b)
-737.6 psi | < Min(**8493** psi , **16994** psi)
ASME external pressure chart CS-2 A = **0.001334**

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

$\sigma_{Sm} \leq$		*1*·	psi	= $E_{sw} \cdot \sigma_{allS}$	(1-3)
σ_{Sm} =	psi	≤2·	psi	= $2 \cdot \sigma_{allS}$	(4-7)

For σSm < 0: | σ_{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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = **23902** psi $\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}
σ_S = | **-737.6** psi | + | **-23164** psi | ≤ **26929** psi

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

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

Strength condition 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	**2.547e+7** psi	**2.547e+7** psi
Channel	psi	psi

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

σ_S = **23902** psi ≤ *54515* psi $=S_{PSs}$

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

σ_C = **0** psi ≤ *0* psi $=S_{PSc}$

Geometric conditions:

valid

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

If: Tube sheet thickness= *3.062* 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·σ_{all} (a) or 2 · Yield strength (b) at operation
54515 psi = 3· *17952* psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

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

Step 1

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

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

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

Step 2

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

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

Step 3

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

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D_0^2}}} = \frac{31.75\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 0\ \text{mm²}}{\pi \cdot (870.2\ \text{mm})^2}}} = 31.75\ \text{mm}$$

$$d^* = Max\begin{cases}d_1^* \\ d_2^*\end{cases}$$

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

$$d_2^* = \left(d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho\right) \Leftrightarrow d_2^* = \left(25.4\ \text{mm} - 2 \cdot 2.108\ \text{mm} \cdot \frac{175622\ \text{N/mm²}}{175622\ \text{N/mm²}} \cdot \frac{71.91\ \text{N/mm²}}{123.8\ \text{N/mm²}} \cdot 0.95\right)$$

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

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

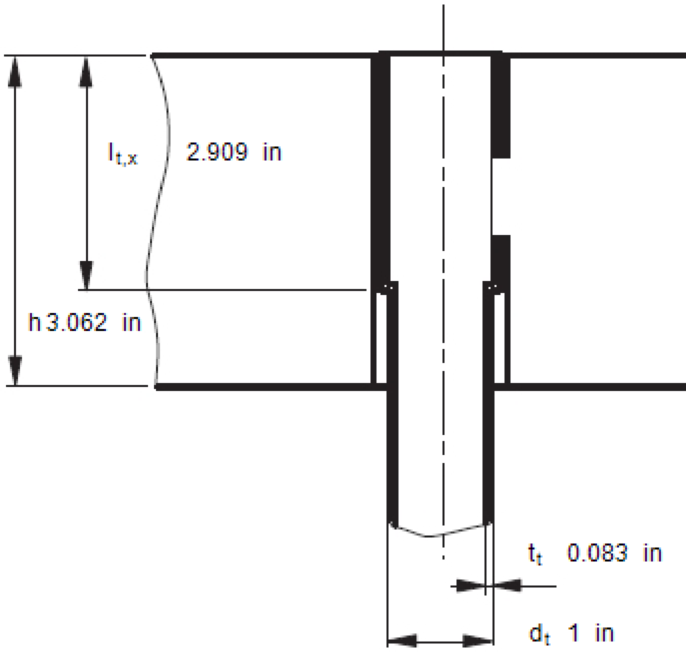
Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

Configuration of the tubesheet (a, b, c, d)		Type	*b*	
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	
Internal operating pressure shell side		P_s	*150*	psi
Internal operating pressure tube side		P_t	*400*	psi
Minimum shell-side operating pressure		$P_{s,min}$	0	psi
Minimum tube-side operating pressure		$P_{t, min}$	0	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	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

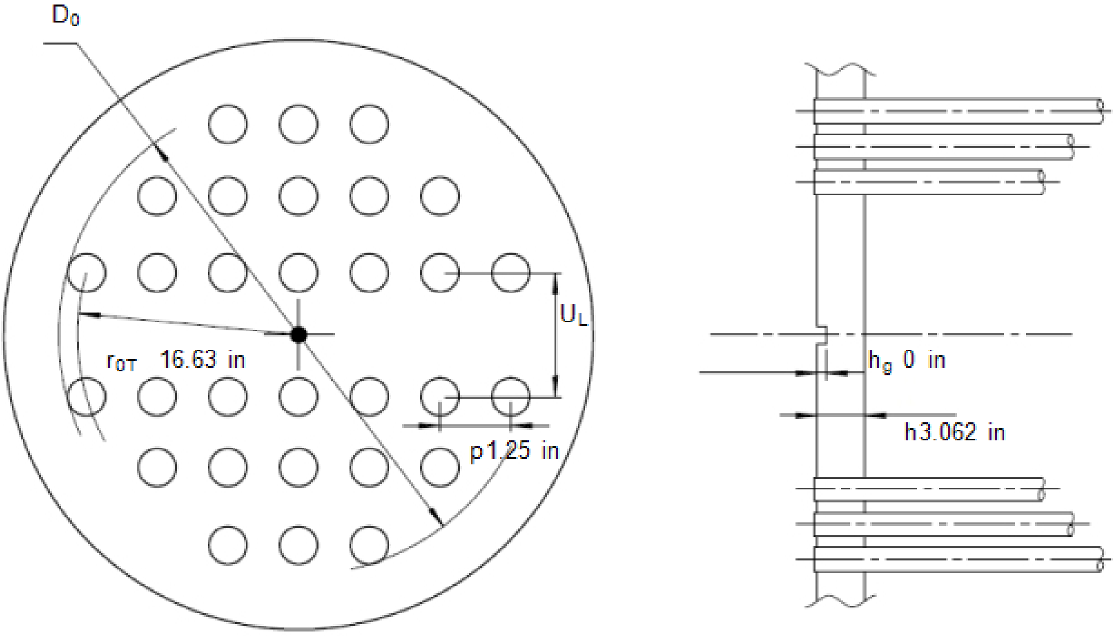
Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	0	in	0	in	0	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
Modulus of elasticity		*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion		*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength		*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature		1000	°F	1000	°F	1000	°F
Allow. stress		*17952*	psi	*10430*	psi	*17952*	psi
Prim.+sec. str.		*54515*	psi			*54515*	psi
Properties for testing at 20°C							
Strength	*)	33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

Additional specifications for the geometry and loading
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*
Tube pattern	(1=Triangle, 2=Square)		*1*
Number of tubes		N_t	*649*



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.95**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*16.63*	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		in²
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	*161.9*	in
Unsupported tube span for buckling	l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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'	*6.389*	1E-6/°F
Channel at T'_c	α'_c		1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*6.389*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F
Flange (Type bcd):			
Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**8.801**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**0.9895**	in

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

Results acc. 4.18.8.4

Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**366642**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2868**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6154**	
Type abc: Coefficients for shell pressure	δ_S	**0.1982**	mm^3/N
β_S **8.522** 1/ft; k_S **21840** lbf	λ_S	**883439**	psi

Step 2

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

Step 3

Effective modulus of el. tubesheet — Fig. 4.18.1-2	E*	**6722554**	psi
Ratio of elasticity tubesheet	E*/E	**0.2639**	
effective Poisson's ratio tubesheet	ν*	**0.3634**	
Parameter for table 4.18.3	X_a	**3.961**	

Z_d **0.02465** Z_v **0.06434** Z_m **0.3718** Z_a **6.529** Z_w **0.06434**

Step 4

Diameter ratio = A/D0				K	**1.182**
F	**0.4872**	Φ	**0.6643**	Q_1	**-0.02269**
Q_{z1}	**2.854**	Q_{z2}	**6.88**	U	**13.76**

Step 5, coefficients

γ(*)	**-0.04727** in	ω_S	**2.687** in²	ω_S*	**-2.656** in²
ω_C	**0** in²	ω_C*	**9.639** in²	γ_b	**-0.06045**

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	**-1252** psi
P_W	**165.4** psi	P_{rim}	**0** psi	P_e	**-0.5044** psi

Step 7

Q_2 **-2829** lbf Q_3 **38.2** F_m **19.18**

Strength condition for the tubesheet bending stress, case 4

σ = **6333** psi < 1.5 · σ_B = 1.5· *17952* psi case 1-3
< S_{PS} = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = **14362** psi

Step 9

F_{tmin} **-144.1** F_{tmax} **305.5**
x_{min} **0.9981** x_{max} **3.961**
$\sigma_{T,1}$ **-431.6** psi $\sigma_{T,2}$ **915.4** psi

σ_{tmax} = **915.4** psi ≤ σ_T = *10430* psi for calculation case 1-3
≤2 · σ_T = **20860** psi for calculation case 4-7

Tube weld force W_t = **218.9** lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

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

│σ_{tmin}│ = │ **-431.6** psi │ ≤S_{tb} = **6123** 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 = *0.1875* in : (calculation case)
σ_{Sm} ≤ *1·* *17952* psi = $E_{sw}·\sigma_{allS}$ (1-3)

σ_{Sm} = **-22.59** psi ≤2· *17952* psi = $2·\sigma_{allS}$ (4-7)

For σSm < 0: │ σ_{Sm} │ < Min(B, A·E/2) acc. UG-23(b)
-22.59 psi < Min(**8493** psi , **16994** psi)
ASME external pressure chart CS-2 A = **0.001334**

Region of increased thickness t_{1s} = in : (calculation case)
σ_{Sm} ≤ *1·* psi = $E_{sw}·\sigma_{allS}$ (1-3)

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

For σSm < 0: │ σ_{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

σ_S = │σ_{Sm}│ + │σ_{Sb}│ = **7616** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}
σ_S = │ **-22.59** psi │ + │ **-7593** psi │ ≤ **54515** psi

σ_C = │σ_{Cm}│ + │σ_{Cb}│ = **0** psi ≤1.5 · σ_{allC} or S_{PSc}
σ_C = │ **0** psi │ + │ **0** psi │ ≤ **0** psi

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

Strength condition 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	**2.547e+7** psi	**2.547e+7** psi
Channel	psi	psi

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

$\sigma_S =$ **7616** psi ≤ *54515* psi $= S_{PSs}$

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

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

Geometric conditions:

valid

Strength condition for linked modules (Connection activated: No):
If: Tube sheet thickness= *3.062* 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
54515 psi = 3· *17952* psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

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

Step 1

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

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

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

Step 2

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

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

Step 3

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

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

$$d^* = Max\begin{cases}d_1^* \\ d_2^*\end{cases}$$

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

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

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

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	*b*	
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	
Internal operating pressure shell side	P_s	*150*	psi
Internal operating pressure tube side	P_t	*400*	psi
Minimum shell-side operating pressure	$P_{s,min}$	0	psi
Minimum tube-side operating pressure	$P_{t,\ min}$	0	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=Ps,min) with differential thermal expansion			

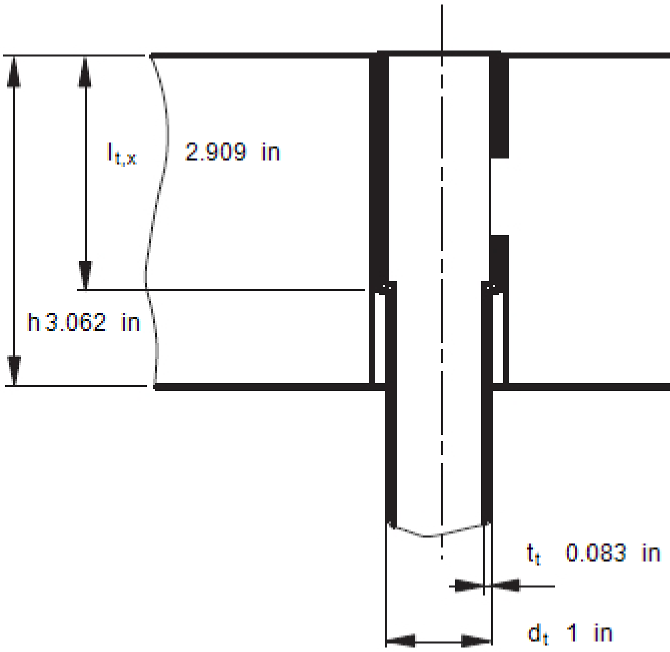
Tubesheet material	*K02700-SA-516-70-Class:-Size:*
Tube material	*K01807-SA-214--Class:-Size:*
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*

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

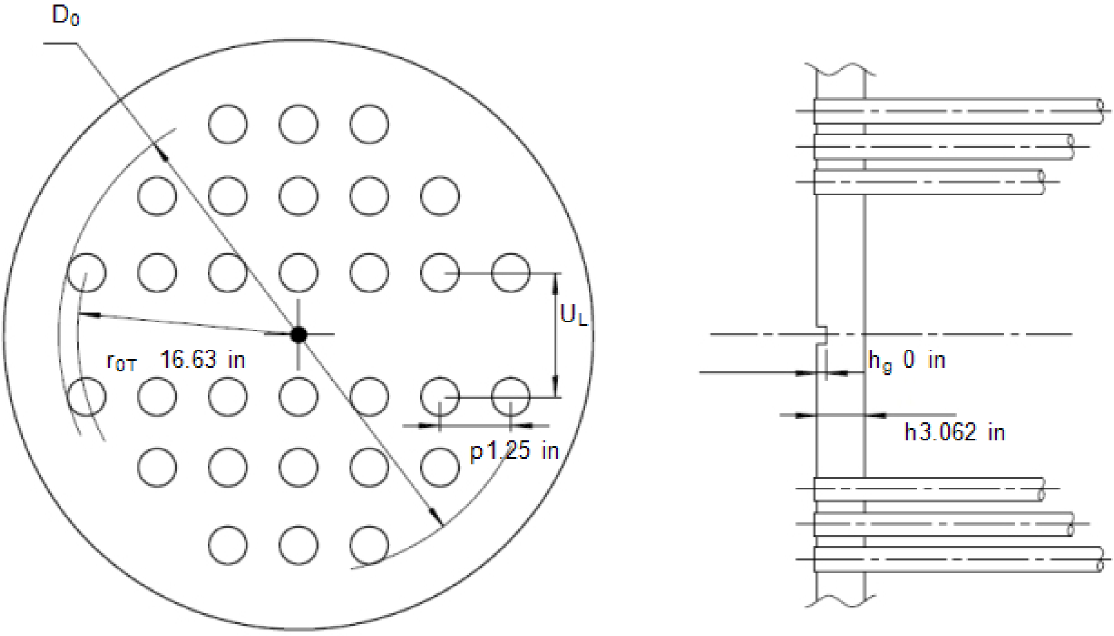
Properties for the selected load case temperature						
Strength operat.	17952	psi	10430	psi	17952	psi
Safety operation	1		1		1	
Modulus of elasticity	*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion	*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength	*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature	1000	°F	1000	°F	1000	°F
Allow. stress	*17952*	psi	*10430*	psi	*17952*	psi
Prim.+sec. str.	*54515*	psi			*54515*	psi
Properties for testing at 20°C						
Strength *)	33939	psi	23496	psi	33939	psi
Safety factor	1		1		1	
Yield strength	37710	psi	26107	psi	37710	psi
Tensile strength	70343	psi	47137	psi	70343	psi

Additional specifications for the geometry and loading
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*
Tube pattern	(1=Triangle, 2=Square)		*1*
Number of tubes		N_t	*649*



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.95**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*16.63*	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		in²
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	*161.9*	in
Unsupported tube span for buckling	l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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'	*6.389*	1E-6/°F
Channel at T'_c	α'_c		1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*6.389*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F
Flange (Type bcd):			
Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512301**	lbf
Total req. bolt area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.235**	in

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

Results acc. 4.18.8.4

Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**512774**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2868**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1\text{-}N_t \cdot (0.5 \cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1\text{-}N_t \cdot (0.5 \cdot d_i TUBE/a_0)^2$	x_t	**0.6154**	
Type abc: Coefficients for shell pressure	δ_S	**0.1982**	mm^3/N
β_S **8.522** 1/ft k_S **21840** lbf	λ_S	**883439**	psi

Step 2

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

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2	E*	**6722554**	psi
Ratio of elasticity tubesheet		E*/E	**0.2639**	
effective Poisson's ratio tubesheet		ν*	**0.3634**	
Parameter for table 4.18.3		X_a	**3.961**	

Z_d **0.02465** Z_v **0.06434** Z_m **0.3718** Z_a **6.529** Z_w **0.06434**

Step 4

Diameter ratio = A/D0				K	**1.182**
F	**0.4872**	Φ	**0.6643**	Q_1	**-0.02269**
Q_{z1}	**2.854**	Q_{z2}	**6.88**	U	**13.76**

Step 5, coefficients

γ(*)	**-0.04727**	in	ω_S	**2.687**	in²	ω_S*	**-2.656** in²
ω_C	**0**	in²	ω_C*	**9.639**	in²	γ_b	**-0.06045**

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'	**860900**	psi	P_γ	**-1252** psi
P_W	**231.3**	psi	P_{rim}	**180.8**	psi	P_e	**-400** psi

Step 7

Q_2 **-7048** lbf Q_3 **0.09741** F_m **0.0975**

Strength condition for the tubesheet bending stress, case 5

σ =	**25533**	psi	< 1.5 · σ_B	= 1.5·	*17952*	psi	case 1-3
			< S_{PS}	=	*54515*	psi	case 4-7

Step 8

Strength condition for the tubesheet shear stress:

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

Step 9

F_{tmin}	-1.081	F_{tmax}	3.805
x_{min}	0	x_{max}	3.961
$\sigma_{T,1}$	-4031 psi	$\sigma_{T,2}$	7579 psi

σ_{tmax} = 7579 psi ≤ σ_T = *10430* psi for calculation case 1-3
≤2 · σ_T = 20860 psi for calculation case 4-7

Tube weld force W_t = 1812 lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t 0.3255 in F_t 181.2 C_t 1.348 F_s 164.2

| σ_{tmin} | = | -4031 psi | ≤S_{tb} = 5679 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 = *0.1875* in : (calculation case)
σ_{Sm} ≤ *1*· *17952* psi = E_{sw}·σ_{allS} (1-3)

σ_{Sm} = 0.06219 psi ≤2· *17952* psi = 2·σ_{allS} (4-7)

For σSm < 0: | σ_{Sm} | < Min(B, A·E/2) acc. UG-23(b)
| 0.06219 psi | < Min(8493 psi , 16994 psi)
ASME external pressure chart CS-2 A = 0.001334
Region of increased thickness t_{1s} = in : (calculation case)
σ_{Sm} ≤ *1*· psi = E_{sw}·σ_{allS} (1-3)

σ_{Sm} = psi ≤2· psi = 2·σ_{allS} (4-7)

For σSm < 0: | σ_{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

σ_S = |σ_{Sm}| + |σ_{Sb}| = 42441 psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}
σ_S = | 0.06219 psi | + | -42441 psi | ≤ 54515 psi

σ_C = |σ_{Cm}| + |σ_{Cb}| = 0 psi ≤1.5 · σ_{allC} or S_{PSc}
σ_C = | 0 psi | + | 0 psi | ≤ 0 psi

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

Strength condition 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	**2.547e+7** psi	**2.547e+7** psi
Channel	psi	psi

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

$\sigma_S =$ **42441** psi ≤ *54515* psi $=S_{PSs}$

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

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

Geometric conditions:

valid

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

If: Tube sheet thickness= *3.062* 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

54515 psi = 3· *17952* psi or 2· *27257* psi

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

T= **700** °F < 1000 °F

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

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

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

Step 1

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

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

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

Step 2

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

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

Step 3

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

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

$$d^* = Max\begin{cases}d_1^*\\ d_2^*\end{cases}$$

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

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

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

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

Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

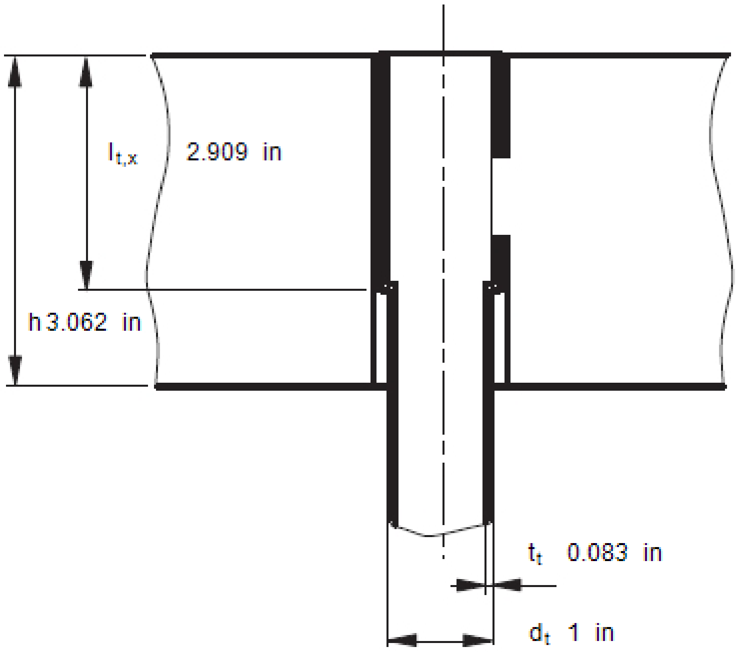
Configuration of the tubesheet (a, b, c, d)	Type	*b*	
Tubesheet integral with shell, gasketed with channel, flange extension			
Channel type (1=Cylinder, 2=Hemispherical)		*1*	
Internal operating pressure shell side	P_s	*150*	psi
Internal operating pressure tube side	P_t	*400*	psi
Minimum shell-side operating pressure	$P_{s,min}$	0	psi
Minimum tube-side operating pressure	$P_{t, min}$	0	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=Pt,min) with differential thermal expansion			

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

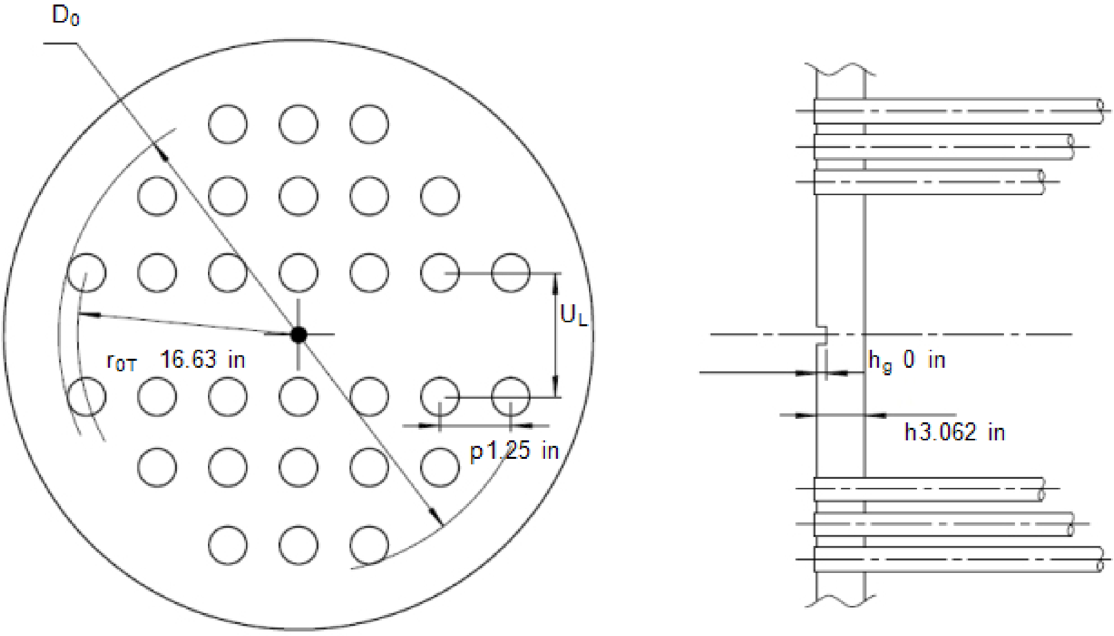
Operation	**Tubesheet**		**Tubes**		**Shell**	
Temperature	*700*	°F	*700*	°F	*700*	°F
Thickness	*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter	*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio	-		*0.3*		*0.3*	
Allowance c_1	0	in	0	in	0	in
Corros. all. c_2	0	in	0	in	0	in
Properties for the selected load case temperature						
Strength operat.	17952	psi	10430	psi	17952	psi
Safety operation	1		1		1	
Modulus of elasticity	*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion	*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength	*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature	1000	°F	1000	°F	1000	°F
Allow. stress	*17952*	psi	*10430*	psi	*17952*	psi
Prim.+sec. str.	*54515*	psi			*54515*	psi
Properties for testing at 20°C						
Strength *)	33939	psi	23496	psi	33939	psi
Safety factor	1		1		1	
Yield strength	37710	psi	26107	psi	37710	psi
Tensile strength	70343	psi	47137	psi	70343	psi

Additional specifications for the geometry and loading
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*
Tube pattern	(1=Triangle, 2=Square)		*1*
Number of tubes		N_t	*649*



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}$/h		ρ	**0.95**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*16.63*	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		in²
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	*161.9*	in
Unsupported tube span for buckling	l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	α_{sm}	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	α_{tm}	*7.3*	1E-6/°F

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'	*6.389*	1E-6/°F
Channel at T'_c	α'_c		1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	α'_s	*6.389*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	α'_s		1E-6/°F
Flange (Type bcd):			
Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. 4.18.5		Shell		Channel	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**0**	lbf
Total req. bolt area	A_m	**0**	in²	**8.801**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**0.9895**	in

Maximum bolt force for all calculation cases	W_{max}	*0*	lbf
Results acc. 4.18.8.4			
Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**366642**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2868**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1-N_t\cdot(0.5\cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1-N_t\cdot(0.5\cdot d_i TUBE/a_0)^2$	x_t	**0.6154**	
Type abc: Coefficients for shell pressure	δ_S	**0.1982**	mm^3/N
β_S **8.522** 1/ft; k_S **21840** lbf	λ_S	**883439**	psi

Step 2

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

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2	E*	**6722554**	psi
Ratio of elasticity tubesheet		E*/E	**0.2639**	
effective Poisson's ratio tubesheet		ν*	**0.3634**	
Parameter for table 4.18.3		X_a	**3.961**	

Z_d **0.02465** Z_v **0.06434** Z_m **0.3718** Z_a **6.529** Z_w **0.06434**

Step 4

Diameter ratio = A/D0				K	**1.182**
F	**0.4872**	Φ	**0.6643**	Q_1	**-0.02269**
Q_{z1}	**2.854**	Q_{z2}	**6.88**	U	**13.76**

Step 5, coefficients

γ(*)	**-0.04727** in	ω_S	**2.687** in²	ω_S*	**-2.656** in²
ω_C	**0** in²	ω_C*	**9.639** in²	γ_b	**-0.06045**

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'	**-46159** psi	P_t'	**0** psi	P_γ	**-1252** psi
P_W	**165.4** psi	P_{rim}	**18.68** psi	P_e	**-21.92** psi

Step 7

Q_2 **-3148** lbf Q_3 **0.9562** F_m **0.5009**

Strength condition for the tubesheet bending stress, case 6

σ = **7189** psi < 1.5 · σ_B = 1.5· *17952* psi case 1-3
< S_{PS} = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = **14362** psi

Step 9

F_{tmin}	**-4.254**	F_{tmax}	**10.6**
x_{min}	**0**	x_{max}	**3.961**
$\sigma_{T,1}$	**-155.6** psi	$\sigma_{T,2}$	**1779** psi

σ_{tmax} = **1779** psi ≤ σ_T = *10430* psi for calculation case 1-3
≤2 · σ_T = **20860** psi for calculation case 4-7

Tube weld force W_t = **425.5** lbf ≤ $W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

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

| σ_{tmin} | = | **-155.6** psi | ≤S_{tb} = **6123** 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 = *0.1875* in : (calculation case)
σ_{Sm} ≤ *1*· *17952* psi = E_{sw}·σ_{allS} (1-3)

σ_{Sm} = **-786.3** psi ≤2· *17952* psi = 2·σ_{allS} (4-7)

For σSm < 0: | σ_{Sm} | < Min(B, A·E/2) acc. UG-23(b)
| **-786.3** psi | < Min(**8493** psi , **16994** psi)
ASME external pressure chart CS-2 A = **0.001334**

Region of increased thickness t_{1s} = in : (calculation case)
σ_{Sm} ≤ *1*· psi = E_{sw}·σ_{allS} (1-3)

σ_{Sm} = psi ≤2· psi = 2·σ_{allS} (4-7)

For σSm < 0: | σ_{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

σ_S = |σ_{Sm}| + |σ_{Sb}| = **12436** psi ≤1.5 · σ_{allS}, S_{PSs} or S_{PSs1}
σ_S = | **-786.3** psi | + | **11650** psi | ≤ **54515** psi

σ_C = |σ_{Cm}| + |σ_{Cb}| = **0** psi ≤1.5 · σ_{allC} or S_{PSc}
σ_C = | **0** psi | + | **0** psi | ≤ **0** psi

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

Strength condition 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	**2.547e+7**	psi	**2.547e+7**	psi
Channel		psi		psi

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

$\sigma_S =$ **12436** psi ≤ *54515* psi $=S_{PSs}$

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

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

Geometric conditions:

valid

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

If: Tube sheet thickness= *3.062* 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·σ_{all} (a) or 2 · Yield strength (b) at operation
54515 psi = 3· *17952* psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

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

Step 1

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

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

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

Step 2

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

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

Step 3

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

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

$$d^* = Max\begin{cases}d_1^*\\ d_2^*\end{cases}$$

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

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

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

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

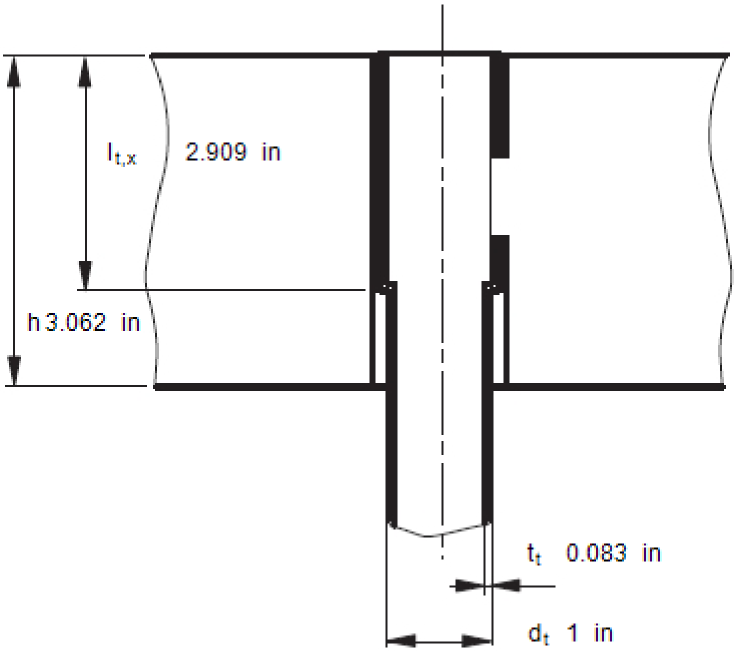
Fixed tubesheets according to ASME VIII Div.2 - 4.18.8

Configuration of the tubesheet (a, b, c, d)		Type	*b*	
Tubesheet integral with shell, gasketed with channel, flange extension				
Channel type (1=Cylinder, 2=Hemispherical)			*1*	
Internal operating pressure shell side		P_s	*150*	psi
Internal operating pressure tube side		P_t	*400*	psi
Minimum shell-side operating pressure		$P_{s,min}$	0	psi
Minimum tube-side operating pressure		$P_{t, min}$	0	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	*K02700-SA-516-70-Class:-Size:*			
Tube material	*K01807-SA-214--Class:-Size:*			
Shell material (Type abc)	*K02700-SA-516-70-Class:-Size:*			

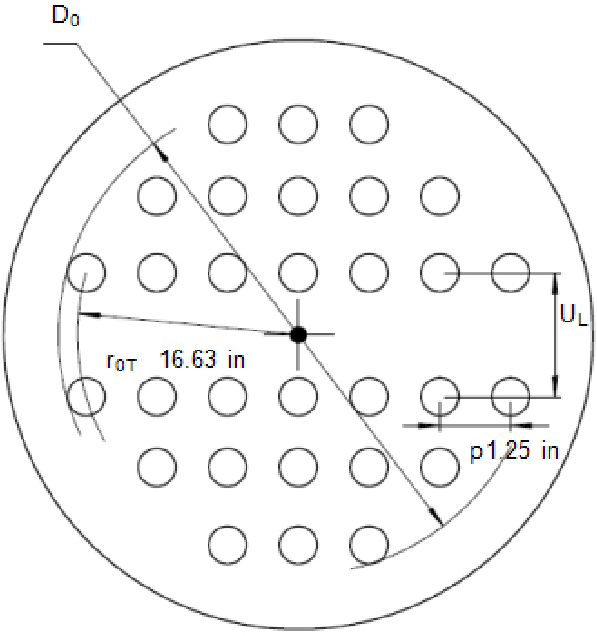
Operation		**Tubesheet**		**Tubes**		**Shell**	
Temperature		*700*	°F	*700*	°F	*700*	°F
Thickness		*3.062*	in	*0.083*	in	*0.1875*	in
Outside diameter		*40.5*	in	*1*	in	*35.13*	in
Poisson's ratio		-		*0.3*		*0.3*	
Allowance	c_1	0	in	0	in	0	in
Corros. all.	c_2	0	in	0	in	0	in
Properties for the selected load case temperature							
Strength operat.		17952	psi	10430	psi	17952	psi
Safety operation		1		1		1	
Modulus of elasticity		*2.547e+7*	psi	*2.547e+7*	psi	*2.547e+7*	psi
Thermal expansion		*7.586*	1E-6/°F	*7.586*	1E-6/°F	*7.586*	1E-6/°F
Yield strength		*27257*	psi	*18655*	psi	*27257*	psi
Limit temperature		1000	°F	1000	°F	1000	°F
Allow. stress		*17952*	psi	*10430*	psi	*17952*	psi
Prim.+sec. str.		*54515*	psi			*54515*	psi
Properties for testing at 20°C							
Strength	*)	33939	psi	23496	psi	33939	psi
Safety factor		1		1		1	
Yield strength		37710	psi	26107	psi	37710	psi
Tensile strength		70343	psi	47137	psi	70343	psi

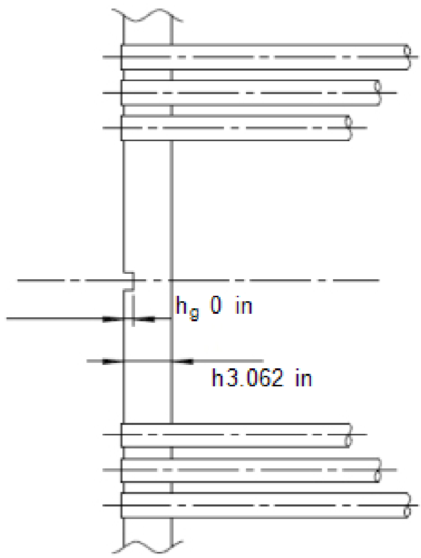
Additional specifications for the geometry and loading
Tubesheet

Tube-tubesheet joint	(1=expanded, 2=welded)		*1*
Tube pattern	(1=Triangle, 2=Square)		*1*
Number of tubes		N_t	*649*



Expanded length of tube in tubesheet		$l_{t,x}$	*2.909*	in
Expanded length ratio $l_{t,x}/h$		ρ	**0.95**	
Radius to outermost tube hole center	Fig. 4.18.2a	r_{0T}	*16.63*	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		in²
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	*161.9*	in
Unsupported tube span for buckling	l	*59*	in
Type of tube support (0.6=tubesheet-tubesheet, 0.8=tubesheet - support plate, 1=plate-plate)	k	**1**	
Equivalent free buckling length k·l	l_t	*59*	in
Bellows inside diameter at its convolution height	D_j	*38.5*	in
Bellows axial rigidity(e.g. 1E+38 without bellows)	K_j	*11388*	lbf/in
Shell weld efficiency factor for axial stress	E_{sw}	*1*	
Material properties for mean operating temperature			
Mean temperature along the shell length	T_{sm}	*550*	°F
Mean temperature along the tube length	T_{tm}	*510*	°F
Mean coefficient of thermal expansion of shell at T_{sm}	$α_{sm}$	*7.3*	1E-6/°F
Mean coefficient of thermal expansion of tubes at T_{tm}	$α_{tm}$	*7.3*	1E-6/°F

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'	$α'$	*6.389*	1E-6/°F
Channel at T'_c	$α'_c$		1E-6/°F
Shell unreinforced (for l1+l'1=0) at T'_s	$α'_s$	*6.389*	1E-6/°F
Shell reinforced acc. 4.18.8.7 at T'_s	$α'_s$		1E-6/°F
Flange (Type bcd):			
Mean contact diameter tubesheet-flange (type c)	G_1		in
Bolt circle diameter	C	*38.88*	in
Number of bolts	n	*68*	
Bolt root diameter	d_B	*0.62*	in
Total bolt area	A_b	**20.53**	in²
Bolt material *G41400-SA-193-B7-Class:-Size:<=64*			
Strength for operation	K_s	25000	psi
Strength for test	K_{sp}	25000	psi
Safety for operation	S_s	1	
Safety for test	S_{sp}	1	
Stress intensification factor for testing (see App.S)	F_s	*1*	

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

Results acc. 4.18.5		**Shell**		**Channel**	
Effective seating width	b		in	**0.2505**	in
Gasket operating force	W	**0**	lbf	**512301**	lbf
Total req. bolt area	A_m	**0**	in²	**20.49**	in²
A_m < actual bolt area = 13245 mm²					
Tubesheet flange thickness	h_r	**0**	in	**1.235**	in

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

Results acc. 4.18.8.4

Max. gasket seating force chan.=0.5(Am+Ab)·Ksp/Ssp, Table 4.16.2	W	**512774**	lbf
Stiffness ratio Bellows/Shell (=1 without bellows)	J	**0.003504**	
Channel shell thickness without allowances	t_c		in
Shell thickness without allowances	t_s	**0.1875**	in
Shell inside diameter corroded (type abc)	D_s	**34.75**	in

Step 1 acc. 4.18.6.4 + 4.18.8.4

Tube material mod. of elast. at tubesheet temperature T	E_{tT}	2.547e+7	psi
Tube material allowable stress basis at T	K_{tT}	12353	psi
Tube material allowable stress safety at T	S_{fT}	1	
Basic ligament efficiency for shear	μ	**0.2**	
Effective tube hole diameter	d*	**0.8915**	in
Effective pitch	p*	**1.25**	in
Effective ligament efficiency for shear	μ*	**0.2868**	
Effective depth of pass partition groove	h_g'	**0**	in
Equivalent radius of outer tube limit circle	a_0	**17.13**	in
Radial channel dimension (type a: Dc/2, else:Gc/2)	a_c	**18.4**	in
Radial shell dimension (type d: Gs/2, else: Ds/2)	a_s	**17.38**	in
Ratio = ac/a0	ρ_C	**1.074**	
Ratio = as/a0	ρ_S	**1.014**	
Parameter = $1\text{-}N_t \cdot (0.5 \cdot d_a TUBE/a_0)^2$	x_s	**0.4471**	
Parameter = $1\text{-}N_t \cdot (0.5 \cdot d_i TUBE/a_0)^2$	x_t	**0.6154**	
Type abc: Coefficients for shell pressure	δ_S	**0.1982**	mm^3/N

β_S	**8.522**	1/ft	k_S	**21840**	lbf	λ_S	**883439**	psi

Step 2

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

Step 3

Effective modulus of el. tubesheet	Fig. 4.18.1-2	E*	**6722554**	psi
Ratio of elasticity tubesheet		E*/E	**0.2639**	
effective Poisson's ratio tubesheet		ν*	**0.3634**	
Parameter for table 4.18.3		X_a	**3.961**	

Z_d	**0.02465**	Z_v	**0.06434**	Z_m	**0.3718**	Z_a	**6.529**	Z_w	**0.06434**

Step 4

Diameter ratio = A/D0				K	**1.182**
F	**0.4872**	Φ	**0.6643**	Q_1	**-0.02269**
Q_{z1}	**2.854**	Q_{z2}	**6.88**	U	**13.76**

Step 5, coefficients

γ(*)	**-0.04727**	in	ω_S	**2.687**	in²	ω_S*	**-2.656**	in²
ω_C	**0**	in²	ω_C*	**9.639**	in²	γ_b	**-0.06045**	

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'	**-46159**	psi	P_t'	**860900**	psi	P_γ	**-1252**	psi
P_W	**231.3**	psi	P_{rim}	**199.5**	psi	P_e	**-421.4**	psi

Step 7

Q_2	**-7368**	lbf	Q_3	**0.09647**	F_m **0.09712**

Strength condition for the tubesheet bending stress, case 7

σ = **26798** psi < 1.5 · σ_B = 1.5· *17952* psi case 1-3
< S_{PS} = *54515* psi case 4-7

Step 8

Strength condition for the tubesheet shear stress:

τ = psi ≤ MIN[0.8σ_B ; 0.533 S_y] = **14362** psi

Step 9

F_{tmin}	-1.078	F_{tmax}	3.797
x_{min}	0	x_{max}	3.961
$\sigma_{T,1}$	-3762 psi	$\sigma_{T,2}$	8443 psi

σ_{tmax} = 8443 psi $\leq \sigma_T$ = *10430* psi for calculation case 1-3
$\leq 2 \cdot \sigma_T$ = 20860 psi for calculation case 4-7

Tube weld force W_t = 2019 lbf $\leq W_{t,all}$ = 0 lbf
(only if weld thickness < tube thickness: enter Wt,all>0 acc. 4.21.2)

r_t 0.3255 in F_t 181.2 C_t 1.351 F_s 164.2

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

Buckling stability acc. 4.18.8.4 Step 9 satisfied

Step 10: Axial membrane stress σSm in the shell

Region of smaller wall thickness t_s = *0.1875* in : (calculation case)
$\sigma_{Sm} \leq$ *1·* *17952* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

For σSm < 0: | σ_{Sm} | < Min(B, A·E/2) acc. UG-23(b)
| -763.6 psi | < Min(8493 psi , 16994 psi)
ASME external pressure chart CS-2 A = 0.001334

Region of increased thickness t_{1s} = in : (calculation case)
$\sigma_{Sm} \leq$ *1·* psi = $E_{sw} \cdot \sigma_{allS}$ (1-3)

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

For σSm < 0: | σ_{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

$\sigma_S = |\sigma_{Sm}| + |\sigma_{Sb}|$ = 23962 psi $\leq 1.5 \cdot \sigma_{allS}$, S_{PSs} or S_{PSs1}
σ_S = | -763.6 psi | + | -23199 psi | $\leq$ 54515 psi

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

Minimum shell length with uniform thickness l_{Sm} 4.595 in
Minimum channel thickness with uniform thickness l_{Cm} 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	**2.547e+7** psi	**2.547e+7** psi
Channel	psi	psi

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

$\sigma_S =$ **23962** psi ≤ *54515* psi $= S_{PSs}$

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

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

Geometric conditions:

valid

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

If: Tube sheet thickness= *3.062* 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
54515 psi = 3· *17952* psi or 2· *27257* psi
(b) under the condition: SigZul not in the creep range:
T= **700** °F < 1000 °F
and: Yield strength < 0.7·tensile strength at room temperature (20°C)

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

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

Step 1

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

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

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

Step 2

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

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

Step 3

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

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

$$d^* = Max\begin{cases}d_1^*\\ d_2^*\end{cases}$$

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

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

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