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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

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 4.18.1 - U Tubesheet Exchanger , Configuration a

Step 1

		LV Soft				ASME		Diff [%]
Equivalent diameter of outer tube limit circle	D_0	295,300	mm	11,626	in	1,16E+01	in	**0,00%**
Basic ligamnet efficient for shear	μ	0,250		0,250	in	2,50E-01		**0,00%**
Effective ligament efficiency for shear	h'_g	0,000	mm	0,000	in	0,00E+00		**0,00%**

Step 2

		LV Soft				ASME	Diff [%]
Ratio Ds/D0	ρ_s	1,066		1,066		1,07E+00	**0,03%**
Ratio Dc/D0	ρ_c	1,059		1,059		1,06E+00	**0,02%**
Tubesheet rim moment due to P_s and P_t	M_{TS}	-713,331	N	-160,363	lbf	-1,60E+02	**0,16%**

Step 3

		LV Soft				ASME	Diff [%]
Effective mod. Elasticity tubesheet	E*	79427,48		1,15E+07		1,15E+07	**0,09%**
Effective Poisson's ratio tubesheet	v*	0,25		2,54E-01		2,54E-01	**0,00%**
Effective tube pitch	p*	29,26	mm	1,15E+00	in	1,15E+00	**0,00%**
Effective ligament efficient for bending	μ*	0,35		3,49E-01		3,49E-01	**0,02%**
Effective tube hole diameter	d*	19,05	mm	7,50E-01	in	7,50E-01	**0,00%**

Step 4

		LV Soft				ASME		Diff [%]
Coefficient for shell pressure, Type abc	δ_S	0,03	mm^3/N	7,02E-06	in^3/lb	6,96E-06	in^3/lb	**0,37%**
Coefficient for moment of shell	ω_S	317,58	mm^2	4,92E-01	in^2	4,89E-01	in^2	**0,58%**
Coefficient for channel pressure, Type aef	δ_C	0,01	mm^3/N	3,99E-06	in^3/lb	3,95E-06	in^3/lb	**0,31%**
Coefficient for moment of channel	ω_C	489,84	mm^2	7,59E-01	in^2	7,54E-01	in^2	**0,76%**

Step 5

		LV Soft		ASME		Diff [%]
Diameter ration A/D0	K		1,11E+00	1,11E+00		**0,00%**
Coefficient	F		9,62E+00	9,45E+00		**1,82%**

Step 6

		LV Soft				ASME		Diff [%]
Rim moment	M*	-218,60	N	-4,91E+01	lb/in	-4,98E+01	lb/in	**1,22%**

Step 7

		LV Soft				ASME		Diff [%]
Bending moment at periphery	M_P	2532,30	N	5,69E+02	lb/in	5,68E+02	lb/in	**0,19%**
Moment at the tubesheet center	M_0	-2053,02	N	-4,62E+02	lb/in	-4,63E+02	lb/in	**0,23%**

Step 8

		LV Soft				ASME		Diff [%]
Bending stress	σ	248,61	N	3,61E+04	psi	3,60E+04	psi	**0,19%**
Bending stress	$2\sigma_B$	249,20	N	3,61E+04	psi	3,60E+04	psi	**0,40%**

Step 8

		LV Soft				ASME		Diff [%]
Bending stress	σ	248,61	N	3,61E+04	psi	3,60E+04	psi	**0,19%**
Bending stress	$2\sigma_B$	249,20	N	3,61E+04	psi	3,60E+04	psi	**0,40%**

Step 9

		LV Soft				ASME		Diff [%]
Shear stress	τ	23,08	N	3,35E+03	psi		psi	
Shear stress (Min 0,8σB; 0,533Sy)		73,45	N	1,07E+04	psi		psi	

Step 10

		LV Soft				ASME		Diff [%]
	σ_S	119,96	N	1,74E+04	psi	1,78E+04	psi	**2,09%**
	$1,5.\sigma_{al}$	186,90	N	2,71E+04	psi	2,70E+04	psi	**0,40%**
	$\sigma_{S,m}$	-1,17	N	-1,70E+02	psi	-1,70E+02	psi	**0,01%**
	$\sigma_{S,b}$	-118,79	N	-1,72E+04	psi	-1,76E+04	psi	**2,10%**
	σ_C	180,67	N	2,62E+04	psi	2,66E+04	psi	**1,64%**
	$1,5.\sigma_{all}$	186,90	N	2,71E+04	psi	2,70E+04	psi	**0,40%**
	$\sigma_{c,m}$	9,26	N	1,34E+03	psi	1,34E+03	psi	**0,01%**
	$\sigma_{c,b}$	171,41	N	2,49E+04	psi	2,53E+04	psi	**1,70%**

Example 4.18.2 - U Tubesheet Exchanger , Configuration d

Step 1

		LV Soft				ASME		Diff [%]
Equivalent diameter of outer tube limit circle	D_0	427,050	mm	16,813	in	16,813	in	**0,00%**
Basic ligamnet efficient for shear	μ	0,167		0,167	in	0,167		**0,00%**
Effective ligament efficiency for shear	h'_g	0,000	mm	0,000	in	0,000		**0,00%**

Step 2

		LV Soft				ASME		Diff [%]
Ratio Ds/D0	ρ_S	1,130		1,130		1,130		**0,01%**
Ratio Dc/D0	ρ_C	1,130		1,130		1,130		**0,01%**
Tubesheet rim moment due to P_s and P_t	M_{TS}	-3491,661	N	-784,957	lbf	-785,000		**0,01%**

Step 3

		LV Soft				ASME		Diff [%]
Effective mod. Elasticity tubesheet	E^*	51736,85		7,50E+06		7,49E+06		**0,17%**
Effective Poisson's ratio tubesheet	ν^*	0,36		3,58E-01		3,58E-01		**0,09%**
Effective tube pitch	p^*	20,45	mm	8,05E-01	in	8,05E-01		**0,01%**
Effective ligament efficient for bending	μ^*	0,28		2,80E-01		2,79E-01		**0,15%**
Effective tube hole diameter	d^*	14,73	mm	5,80E-01	in	5,80E-01		**0,05%**

Step 5

		LV Soft			ASME		Diff [%]
Diameter ration A/D0	K		1,19E+00		1,19E+00		**0,00%**
Coefficient	F		4,20E-01		4,21E-01		**0,17%**

Step 6

		LV Soft			ASME		Diff [%]
Rim moment	M*	-3491,66	N	-7,85E+02 lb/in	-7,85E+02	lb/in	**0,01%**

Step 7

		LV Soft			ASME		Diff [%]
Bending moment at periphery	M_P	-713,53	N	-1,60E+02 lb/in	-1,60E+02	lb/in	**0,38%**
Moment at the tubesheet center	M_0	-10608,55	N	-2,38E+03 lb/in	-2,38E+03	lb/in	**0,04%**

Step 8

		LV Soft			ASME		Diff [%]
Bending stress	σ	-215,19	N	-3,12E+04 psi	-3,13E+04	psi	**0,13%**
Bending stress	$2\sigma_B$	244,18	N	3,54E+04 psi	3,54E+04	psi	**0,04%**

Step 9

		LV Soft			ASME		Diff [%]
Shear stress	τ	23,08	N	3,35E+03 psi		psi	
Shear stress (Min 0,8σB; 0,533Sy)		73,45	N	1,07E+04 psi		psi	

Example 4.18.4 - U Tubesheet Exchanger , Configuration e

Step 1

		LV Soft				ASME		Diff [%]
Equivalent diameter of outer tube limit circle	D_0	666,750	mm	26,250	in	26,250	in	0,00%
Basic ligamnet efficient for shear	μ	0,250		0,250	in	0,250		0,00%
Effective ligament efficiency for shear	h'_g	0,000	mm	0,000	in	0,000		0,00%

Step 2

		LV Soft				ASME		Diff [%]
Ratio Ds/D0	ρ_s	1,233		1,233		1,233		0,03%
Ratio Dc/D0	ρ_c	1,181		1,181		1,181		0,00%
Tubesheet rim moment due to P_s and P_t	M_{TS}	73250,375	N	16467,344	lbf	16470,000		0,02%

Step 3

		LV Soft				ASME		Diff [%]
Effective mod. Elasticity tubesheet	E*	84616,73		1,23E+07		1,23E+07		0,30%
Effective Poisson's ratio tubesheet	v*	0,32		3,18E-01		3,18E-01		0,00%
Effective tube pitch	p*	26,29	mm	1,04E+00	in	1,04E+00		0,01%
Effective ligament efficient for bending	μ*	0,38		3,77E-01		3,86E-01		2,23%
Effective tube hole diameter	d*	16,16	mm	6,36E-01	in	6,36E-01		0,00%

Step 4

		LV Soft				ASME		Diff [%]
Coefficient for shell pressure, Type abc	δ_s		mm^3/N		in^3/lb		in^3/lb	
Coefficient for moment of shell	ω_s	0,00	mm^2	0,00E+00	in^2		in^2	0,00%
Coefficient for channel pressure, Type aef	δ_c	0,04	mm^3/N	1,18E-05	in^3/lb	1,17E-05	in^3/lb	0,34%
Coefficient for moment of channel	ω_c	4524,31	mm^2	7,01E+00	in^2	7,01E+00	in^2	0,04%

Step 5

		LV Soft		ASME	Diff [%]
Diameter ration A/D0	K		1,42E+00	1,42E+00	**0,00%**
Coefficient	F		9,64E-01	9,65E-01	**0,00%**

Step 6

		LV Soft				ASME		Diff [%]
Rim moment	M*	119677,10	N	2,69E+04	lb/in	2,66E+04	lb/in	**1,30%**

Step 7

		LV Soft				ASME		Diff [%]
Bending moment at periphery	M_p	28952,39	N	6,51E+03	lb/in	6,65E+03	lb/in	**2,07%**
Moment at the tubesheet center	M_0	132269,88	N	2,97E+04	lb/in	2,99E+04	lb/in	**0,45%**

Step 8

		LV Soft				ASME		Diff [%]
Bending stress	σ	266,38	N	3,86E+04	psi	3,98E+04	psi	**2,80%**
Bending stress	$2\sigma_{B3}$	298,93	N	4,34E+04	psi	4,32E+04	psi	**0,36%**

Step 9

		LV Soft				ASME		Diff [%]
Shear stress	τ	33,61	N	4,88E+03	psi		psi	
Shear stress (Min 0,8σB; 0,533Sy)		110,32	N	1,60E+04	psi		psi	

E 4.18.1 - U-Tube Heatexchangers - ASME BPVC VIII-2, 2025

U-Tubesheet Heat Exchanger according to ASME VIII Div. 2 - 4.18.7

Configuration of the tubesheet		a	
Tubesheet integral with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operating pressure shell side	P_s	60	psi
Internal operating pressure tube side	P_t	140	psi
Minimum shell-side operating pressure	$P_{s,min}$	-10	psi
Minimum tube-side operating pressure	$P_{t,\ min}$	-15	psi
Internal test pressure shell side	R_{sp}	0	psi
Internal test pressure tube side	P_{tp}	0	psi
Load case (1=Operation, 2+3=Test at 20°C, 4=other)		1	
load case: operation			
Calculation case 4.18.3 (1: Ps=0, 2: Pt=0, 3:Differ.)		1	(1-3)
Tube side pressure acting (Ps=Ps,min)			
Material tubesheet	S31600-SA-240-316-Class:-Size:		
Material shell (Type abc)	S31600-SA-312-TP316-Class:-Size:		
Material tubes	S31600-SA-213-TP316-Class:-Size:		
Mat. channel (Type aef)	S31600-SA-240-316-Class:-Size:		

Load temperature°C	**Tubesheet**	**Shell**	**Tubes**	**Channel**
Temperat.	500 °F	500 °F	500 °F	500 °F
Thickness	0.521 in	0.18 in	0.065 in	0.313 in
Outside diameter	12.94 in	12.75 in	0.75 in	12.94 in
Strength	18072 psi	18072 psi	18072 psi	18072 psi
Safety fac.	1	1	1	1
Modulus of elasticity	2.587e+7 psi	2.587e+7 psi	2.587e+7 psi	2.587e+7 psi
Allow. c_1	0 in	0 in	0 in	0 in
Corr.all. c_2	0 in	0 in	0 in	0 in
Poisson's ratio	v	0.3		0.3
Therm.exp.	17.42 1E-6/K	17.42 1E-6/K	17.42 1E-6/K	17.42 1E-6/K
Yield str.	19986 psi	19986 psi	19986 psi	19986 psi
Limit temperature	932 °F	932 °F	932 °F	932 °F
All.Stress	**18072** psi	**18072** psi	**18072** psi	**18072** psi
Pr.+sec.st	**54215** psi	**54215** psi	**54215** psi	**54215** psi
Test 20°C	**Tubesheet**	**Shell**	**Tubes**	**Channel**
Strength	26759 psi	26759 psi	26759 psi	26759 psi
Safety fac.	1	1	1	1
Modulus of elasticity	2.833e+7 psi	2.833e+7 psi	2.833e+7 psi	2.833e+7 psi
Yield str.	29733 psi	29733 psi	29733 psi	29733 psi
Tensile str.	74694 psi	74694 psi	74694 psi	74694 psi

Mean contact diameter tubesheet-flange (Type cf)	G_1	in
Bolt circle diameter (Type bcdef)	C	in

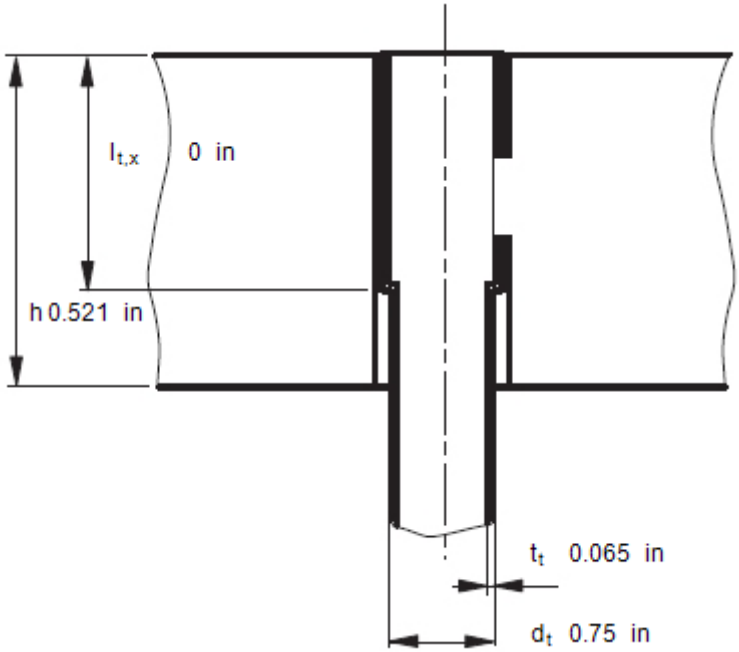
Number of bolts		n	
Bolt root diameter		d_B	in
Total bolt area		A_b	in²
Bolt material			
Strength for operation		K_s	psi
Strength at 20°C (or test)		K_{sp}	psi
Safety for operation		S_s	
Safety at 20°C (or test)		S_{sp}	
Stress enhancement factor acc. App. S		F_s	1.5
Allowable testing stress for bolts		σ	psi
Yield stress (20°C)	Rp0,2RT		psi
Flange material			
Strength operation		K_f	psi
Strength at 20°C (or test)		K_{fp}	psi
Safety for operation		S_f	
Safety at 20°C (or test)		S_{fp}	

Gasket		**Shell Type d,e,f**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in		in
Contact inside diameter	Gi		in		in
Basic seating width	b_0		in		in
Gasket factor (Table 4.16.1)	m				
Gasket seating pressure	Y		psi		psi
Diameter of gasket force	G		in		in
Results acc. 4.18.7 Step 9		**Shell**		**Channel**	
Effective seating width	b		in		in
Initial gasket force	W	**0**	lbf	**0**	lbf
Gasket operation force	W	**0**	lbf	**0**	lbf
Total req. bolt root area	A_m	**0**	in²	**0**	in²
Flange thickness	h_r	**0**	in	**0**	in

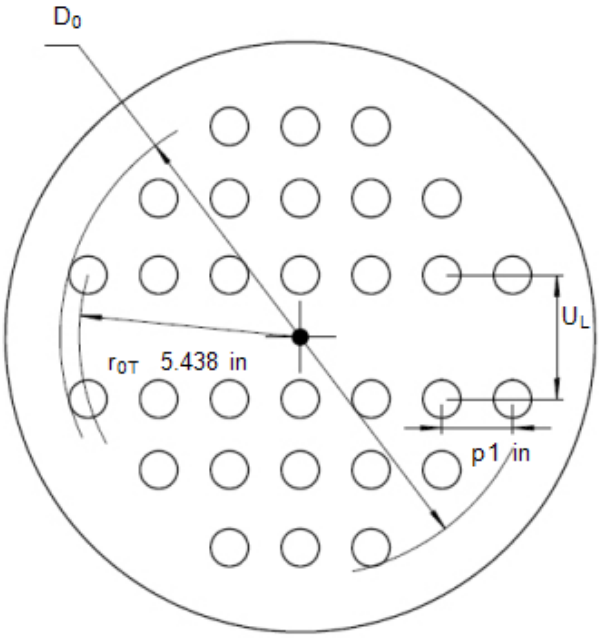
Bolt area in² :

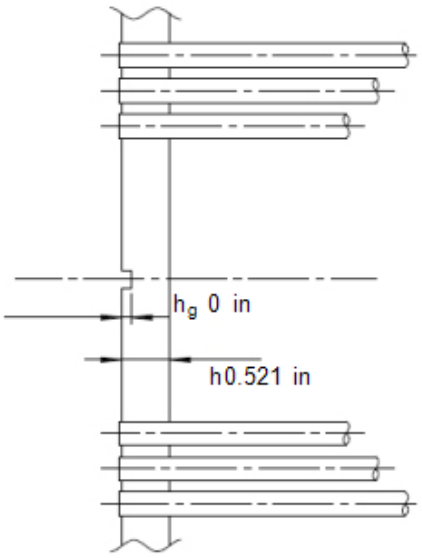
Additional specifications for geometry and loading
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	0	in
Radius to outermost tube hole center	Fig. 4.18.2 a	r_{0T}	5.438	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by Cp	Fig. 4.18.14	A_p		in²
Tube hole pitch (Center distance)		p	1	in





Untubed area UL1·LL1+UL2·LL2...	Fig. 4.18.3	A_L	26.17	in²
Depth of pass partition groove		h_g	0	in
Length ratio of tube expansion ltx/h		ρ	**0**	

Results acc. to 4.18.7

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	Table 4.16.2	W_m	**0**	lbf
Channel thickness without allowances		t_c	**0.313**	in
Shell thickness without allowances		t_s	**0.18**	in
Inside diameter of channel, corroded (Type ade)		D_c	**12.31**	in
Inside diameter of shell, corroded (Type abcd)		D_s	**12.39**	in
Recommended initial tubesheet thickness	4.18.3	h_{in}	**0.1206**	in
Tubesheet thickness without allowances > hin		h	**0.521**	in

Step 1

Equivalent diameter of outer tube limit circle	D_0	**11.63**	in
Basic ligament efficiency for shear	μ	**0.25**	
Effective tubeside pass partition groove depth	h_g'	**0**	in

Step 2

Ratio Ds/D0 (Type abc) or Gs/D0 (Type def)	ρ_S	**1.066**	
Ratio Dc/D0 (Type aef) or Gc/D0 (Type bcd)	ρ_C	**1.059**	
Tubesheet rim moment due to P_s and P_t	M_{TS}	**-160.4**	lbf

Step 3

Effective mod. elasticity tubesheet	E*	**1.152e+7**	psi
Effective Poisson's ratio of tubesheet	v*	**0.2539**	
Effective tube pitch	p*	**1.152**	in
Effective ligament efficiency for bending	μ*	**0.349**	
Effective tube hole diameter	d*	**0.75**	in

Step 4

Coefficient for shell pressure, Type abc	δ_S	**0.02587**	mm^3/N
Coefficient for moment of shell	ω_S	**0.4922**	in²
Coefficient for channel pressure, Type aef	δ_c	**0.01472**	mm^3/N
Coefficient for moment of channel	ω_C	**0.7593**	in²

Step 5

Diameter ratio = A/D0	K	**1.113**	
Coefficient	F	**9.618**	

Step 6

Rim moment	M*	**-49.14**	lbf

Step 7

Bending moment at periphery	M_p	**569.3**	lbf
Moment at the tubesheet center	M_0	**-461.5**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **36058** psi < **36143** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **3347** psi ≤ **10653** psi = $MIN[0.8\sigma_B ; 0.533\ S_y]$

Strength condition satisfied

Step 10: Absolute values of stress σS in the shell and und σC in the channel

σ_S = **17399** psi < **27107** psi = $1.5 \cdot \sigma_{all}$

$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ = **-169.6** psi + **-17230** psi

σ_C = **26203** psi < **27107** psi = $1.5 \cdot \sigma_{all}$

$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ = **1343** psi + **24860** psi

Shell length, uniform thickness > l_{Sm} = 0	or	**2.688**	in
Channel length, uniform thickness > l_{Cm} = 0	or	**3.534**	in

Strength condition acc. to ASME VIII/2 18.7-12.5.10 satisfied

Step 11 option 3: If the strength condition of step 10 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 allows also the reduction of the elastic modulus of the shell and/or the channel.

Geometric conditions:

valid

Equations acc. to 4.18.7 (in SI-Units)

4.18.3 If: Tubesheet thickness = 0.521 in < 0.75 in
= Tube outside diameter, the tube sheet deflection should be considered

Allowable primary and secondary stress in the shell acc. to UG-23(e):
S_{PSs} = 3·σ_{all} (a) or 2·Yield strength (b) for operation
54215 psi = 3· **18072** psi or 2· 19986 psi
(b) under the condition: σ_{all} not in the creep range
T= **500** °F < 932 °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

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

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

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot \left| p_T - p_S \right| = \frac{1}{(4 \cdot 0.25)} \cdot \frac{295.3\ \text{mm}}{(0.8 \cdot 124.6\ \text{MPa})} \cdot \left| 0.9653\ \text{MPa} - 0.4137\ \text{MPa} \right| = 3.064\ \text{mm}$$

Step 1

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

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

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

Step 2

$$M_{TS120} = \frac{D0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S{}^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho C^2 + 1) \cdot P_t \right] =$$

$$\frac{(295.3\ \text{mm})^2}{16} \cdot [((1.066 - 1)((1.066)^2 + 1) \cdot 0.4137\ \text{MPa}) - (1.059 - 1)((1.059)^2 + 1) \cdot 0.9653\ \text{MPa}] = -713.3\ \text{N}$$

Step 3

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

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D0^2}}} = \frac{25.4\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 16884\ \text{mm}^2}{\pi \cdot (295.3\ \text{mm})^2}}} = 29.26\ \text{mm}$$

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

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

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

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

Step 4

Type abc:	β_S	**14.5**	1/ft	k_S	**33401**	lbf	λ_S	**3.256e+7**	psi
Type aef:	β_C	**10.97**	1/ft	k_C	**132878**	lbf	λ_C	**1.132e+8**	psi

Step 5

$$F=\frac{(1-v^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.2539)}{79427\ \text{MPa}}\cdot(224485\ \text{MPa}+780316\ \text{MPa}+178400\ \text{MPa}\cdot\ln(1.113))=9.618$$

Step 6

$$M^*=M_{TS}+\omega_C\cdot P_c-\omega_S\cdot P_s+M_{add}=-713.3\ \text{N}+489.8\ \text{mm}^2\cdot 0.9653\ \text{MPa}-317.6\ \text{mm}^2\cdot -0.06895\ \text{MPa}+0\ \text{N}=-218.6\ \text{N}$$

M_{add} = 0 = **0** lbf

4.18.7.4 acc. 4.18.7.5

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

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

σ			**or**	**σ acc. 4.18.7.5**		**< 2· σ_B**	
σ =	**36058**	psi	or	**-67799**	psi	< 2·	**18072** psi

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

τ			**or**	**τ acc. 4.18.7.5**		**≤ MIN[0.8σ_B ; 0.533 S_y]**	
τ =	**3347**	psi	or	**3347**	psi	≤	**10653** psi

Strength condition satisfied

If the strength condition in step 8 or 9 is violated, the tubesheet thickness must be increased.
Actual thickness 0.521 in

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

in MPa:	**σ_m**		**σ_b**			**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**-1.169**	+	**-118.8**	=	**120**	< 1.5·	**124.6**	or	**373.8**
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**9.259**	+	**171.4**	=	**180.7**	< 1.5·	**124.6**	or	**373.8**

*) Simply supported (N) acc. 4.18.7.5

Strength condition acc. to ASME VIII/2 18.7-12.5.10 satisfied

Step 11: The modulus of elasticity is reduced: N (Y=Yes,N=No)

Modulus of elasticity	elastic	Option 3
Shell	**2.587e+7** psi	**2.587e+7** psi
Channel	**2.587e+7** psi	**2.587e+7** psi

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

σ_S = **17399** psi ≤ **54215** psi = S_{PSs}

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

Analogously for the channel:

σ_C = **26203** psi ≤ **54215** psi = S_{PSc}

E.4.18.2 - U-Tube Heatexchangers - ASME BPVC VIII-2, 2025

U-Tubesheet Heat Exchanger according to ASME VIII Div. 2 - 4.18.7

Configuration of the tubesheet		d	
Tubesheet gasketed with shell and channel			
Channel type (1=Cylinder, 2=Hemispherical)		1	(1,2)
Internal operating pressure shell side	P_s	10	psi
Internal operating pressure tube side	P_t	135	psi
Minimum shell-side operating pressure	$P_{s,min}$	-15	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 4.18.3 (1: Ps=0, 2: Pt=0, 3:Differ.)		1	(1-3)
Tube side pressure acting (Ps=Ps,min)			
Material tubesheet	K02801-SA-285-C-Size:t ≤ 50		
Material shell (Type abc)			
Material tubes	C44300-SB-111--Class:O61-Size:<75		
Mat. channel (Type aef)			

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	300	°F		°F	300	°F		°F
Thickness	1.405	in		in	0.065	in		in
Outside diameter	20	in		in	0.625	in		in
Strength	17707	psi		psi	9993	psi		psi
Safety fac.	1				1			
Modulus of elasticity	2.83e+7	psi		psi	1.538e+7	psi		psi
Allow. c_1	0	in		in	0	in		in
Corr.all. c_2	0.125	in		in	0	in		in
Poisson's ratio		v	0.3				0.3	
Therm.exp.	17	1E-6/K		1E-6/K	17.99	1E-6/K		1E-6/K
Yield str.	0	psi		psi	0	psi		psi
Limit temperature	932	°F		°F	932	°F		°F
All.Stress	**17707**	psi	**0**	psi	**9993**	psi	**0**	psi
Pr.+sec.st	**53122**	psi	**0**	psi	**29979**	psi	**0**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	26759	psi	0	psi	13053	psi	0	psi
Safety fac.	1				1			
Modulus of elasticity	2.83e+7	psi		psi	1.598e+7	psi		psi
Yield str.	29733	psi		psi	14504	psi		psi
Tensile str.	55114	psi		psi	44961	psi		psi

Mean contact diameter tubesheet-flange (Type cf)	G_1		in
Bolt circle diameter (Type bcdef)	C	21.65	in

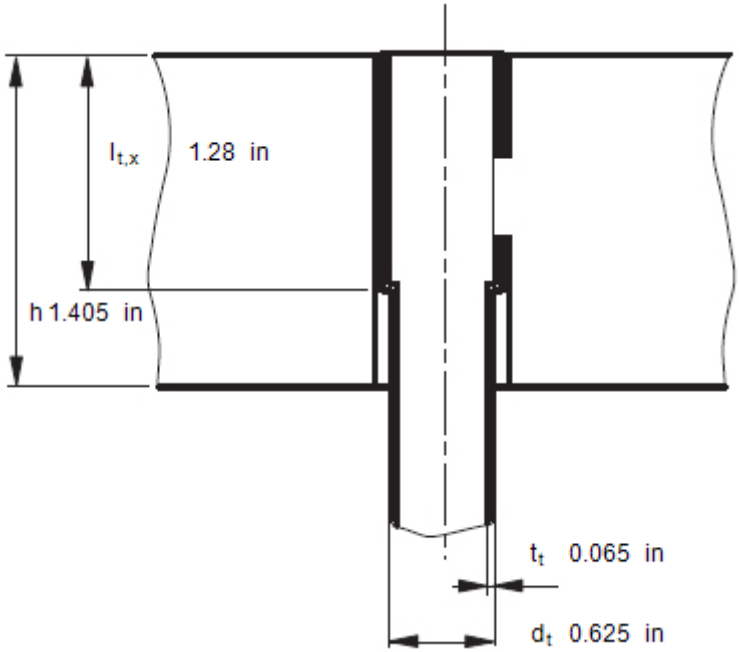
Number of bolts		n		
Bolt root diameter		d_B		in
Total bolt area		A_b		in²
Bolt material	K50100-SA-193-B5-Class:-Size:<=100			
Strength for operation		K_s	20015	psi
Strength at 20°C (or test)		K_{sp}	20015	psi
Safety for operation		S_s	1	
Safety at 20°C (or test)		S_{sp}	1	
Stress enhancement factor acc. App. S		F_s	0	
Allowable testing stress for bolts		σ	**0**	psi
Yield stress (20°C)		Rp0,2RT	0	psi
Flange material	K02801-SA-285-C-Class:-Size:			
Strength operation		K_f	15664	psi
Strength at 20°C (or test)		K_{fp}	15664	psi
Safety for operation		S_f	1	
Safety at 20°C (or test)		S_{fp}	1	

Gasket		**Shell Type d,e,f**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in		in
Contact inside diameter	Gi		in		in
Basic seating width	b_0		in		in
Gasket factor (Table 4.16.1)	m				
Gasket seating pressure	Y		psi		psi
Diameter of gasket force	G	19	in	19	in
Results acc. 4.18.7 Step 9		**Shell**		**Channel**	
Effective seating width	b		in		in
Initial gasket force	W	147000	lbf	162000	lbf
Gasket operation force	W	147000	lbf	162000	lbf
Total req. bolt root area	A_m	**7.344**	in²	**8.094**	in²
Flange thickness	h_r		in		in

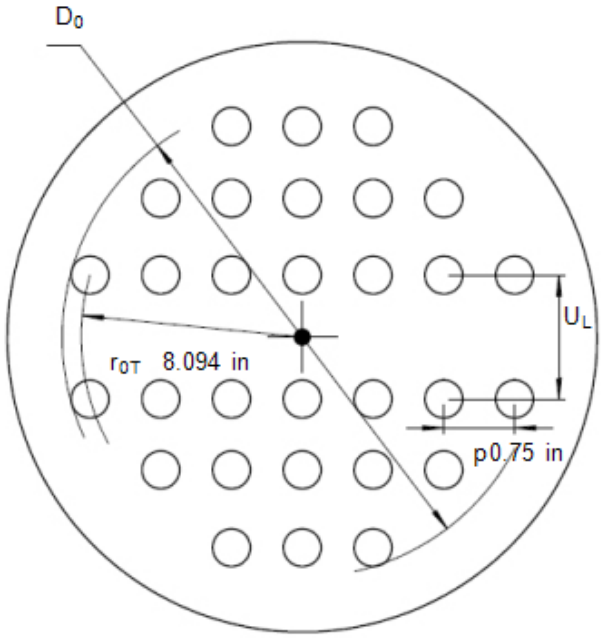
Bolt area in² :

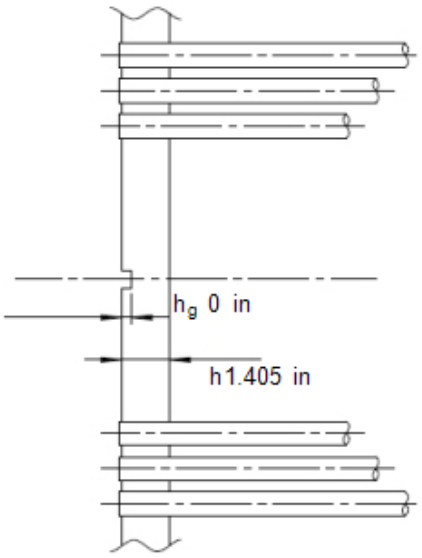
Additional specifications for geometry and loading
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	1.28	in
Radius to outermost tube hole center	Fig. 4.18.2 a	r_{0T}	8.094	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by Cp	Fig. 4.18.14	A_p		in²
Tube hole pitch (Center distance)		p	0.75	in





Untubed area UL1·LL1+UL2·LL2...	Fig. 4.18.3	A_L	29.42	in²
Depth of pass partition groove		h_g	0	in
Length ratio of tube expansion ltx/h		ρ	1	

Results acc. to 4.18.7

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	Table 4.16.2	W_m	162000	lbf
Channel thickness without allowances		t_c		in
Shell thickness without allowances		t_s		in
Inside diameter of channel, corroded (Type ade)		D_c		in
Inside diameter of shell, corroded (Type abcd)		D_s		in
Recommended initial tubesheet thickness	4.18.3	h_{in}	**0.267**	in
Tubesheet thickness without allowances > hin		h	**1.28**	in
Step 1				
Equivalent diameter of outer tube limit circle		D_0	**16.81**	in
Basic ligament efficiency for shear		μ	**0.1667**	
Effective tubeside pass partition groove depth		h_g'	**0**	in
Step 2				
Ratio Ds/D0 (Type abc) or Gs/D0 (Type def)		ρ_S	**1.13**	
Ratio Dc/D0 (Type aef) or Gc/D0 (Type bcd)		ρ_C	**1.13**	
Tubesheet rim moment due to P_s and P_t		M_{TS}	**-785**	lbf
Step 3				
Effective mod. elasticity tubesheet		E*	**7265906**	psi
Effective Poisson's ratio of tubesheet		ν*	**0.3627**	
Effective tube pitch		p*	**0.8052**	in
Effective ligament efficiency for bending		μ*	**0.2734**	
Effective tube hole diameter		d*	**0.5851**	in
Step 4				
Coefficient for moment of shell		ω_S	**0**	in²
Coefficient for moment of channel		ω_C	**0**	in²
Step 5				
Diameter ratio = A/D0		K	**1.19**	
Coefficient		F	**0.4308**	
Step 6				
Rim moment		M*	**-785**	lbf
Step 7				
Bending moment at periphery		M_p	**-149.6**	lbf
Moment at the tubesheet center		M_0	**-2378**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **-31851** psi < **35415** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **2955** psi ≤ **0** psi = $MIN[0.8\sigma_B ; 0.533\ S_y]$

Step 9: Shear stress Tau > Min(0.8*SigZul,0.533*SigYield), tubesheet too thin

Step 10: Absolute values of stress σS in the shell and und σC in the channel

σ_S = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ = **0** psi + **0** psi

σ_C = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ = **0** psi + **0** psi

Shell length, uniform thickness > l_{Sm} = 0 or in

Channel length, uniform thickness > l_{Cm} = 0 or in

4.18.7.4 Step 10 not required for configuration d

Step 11 option 3: If the strength condition of step 10 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 allows also the reduction of the elastic modulus of the shell and/or the channel.

Geometric conditions:

valid

Equations acc. to 4.18.7 (in SI-Units)

4.18.3 If: Tubesheet thickness = 1.405 in < 0.625 in
= Tube outside diameter, the tube sheet deflection should be considered

Allowable primary and secondary stress in the shell acc. to UG-23(e):
S_{PSs} = 3·σ_{all} (a) or 2·Yield strength (b) for operation
0 psi = 3· **0** psi or 2· psi
(b) under the condition: σ_{all} not in the creep range
T= **300** °F < °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

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

$$h = t_{vB} - c_{1B} - c_{2B} = 35.69\ \text{mm} - 0\ \text{mm} - 3.175\ \text{mm} = 32.51\ \text{mm}$$

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot \left| p_T - p_S \right| = \frac{1}{(4 \cdot 0.1667)} \cdot \frac{427.1\ \text{mm}}{(0.8 \cdot 122.1\ \text{MPa})} \cdot \left| 0.9308\ \text{MPa} - 0.06895\ \text{MPa} \right| = 6.783\ \text{mm}$$

Step 1

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

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

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

Step 2

$$M_{TS120} = \frac{D0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S{}^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho C^2 + 1) \cdot P_t \right] =$$

$$\frac{(427.1\ \text{mm})^2}{16} \cdot [((1.13 - 1)((1.13)^2 + 1) \cdot 0.06895\ \text{MPa}) - (1.13 - 1)((1.13)^2 + 1) \cdot 0.9308\ \text{MPa}] = -3492\ \text{N}$$

Step 3

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

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D0^2}}} = \frac{19.05\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 18981\ \text{mm}^2}{\pi \cdot (427.1\ \text{mm})^2}}} = 20.45\ \text{mm}$$

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

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

$$d2^* = d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho = 15.88\ \text{mm} - 2 \cdot 1.651\ \text{mm} \cdot \frac{106044\ \text{MPa}}{195123\ \text{MPa}} \cdot \frac{68.9\ \text{MPa}}{122.1\ \text{MPa}} \cdot 1 = d2^*$$

$$\mu^* = \frac{(p^* - d^*)}{d^*} = \frac{(20.45\ \text{mm} - 14.86\ \text{mm})}{14.86\ \text{mm}} = 0.2734$$

Step 4

Type abc:	β_S	1/ft	k_S	lbf	λ_S	**0**	psi
Type aef:	β_C	1/ft	k_C	lbf	λ_C	**0**	psi

Step 5

$$F=\frac{(1-v^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.3627)}{50097\ \text{MPa}}\cdot(0\ \text{MPa}+0\ \text{MPa}+195123\ \text{MPa}\cdot\ln(1.19))=0.4308$$

Step 6

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

M_{add} = (Gc-Gs)*Wm/(2* PI *D0) = **0** lbf

4.18.7.4 acc. 4.18.7.5

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

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

σ			**or**	**σ acc. 4.18.7.5**		**< 2· σ_B**	
σ =	**-31851**	psi	or	**-31851**	psi	< 2· **17707**	psi

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

τ			**or**	**τ acc. 4.18.7.5**		**≤ MIN[0.8σ_B ; 0.533 S_y]**	
τ =	**2955**	psi	or	**2955**	psi	≤ **0**	psi

Step 9: Shear stress Tau > Min(0.8*SigZul,0.533*SigYield), tubesheet too thin

If the strength condition in step 8 or 9 is violated, the tubesheet thickness must be increased.
Actual thickness 1.405 in

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

in MPa:	**σ_m**		**σ_b**		**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**0**	+	**0**	= **0**	< 1.5·	**0**	or	**0**
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**0**	+	**0**	= **0**	< 1.5·	**0**	or	**0**

*) Simply supported (N) acc. 4.18.7.5

4.18.7.4 Step 10 not required for configuration d

Step 11: The modulus of elasticity is reduced: N (Y=Yes,N=No)

Modulus of elasticity	elastic	Option 3
Shell	psi	psi
Channel	psi	psi

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

σ_S = **0** psi ≤ **0** psi = S_{PSs}

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

Analogously for the channel:

σ_C = **0** psi ≤ **0** psi = S_{PSc}

E.4.18.4 - U-Tube Heatexchangers - ASME BPVC VIII-2, 2025

U-Tubesheet Heat Exchanger according to ASME VIII Div. 2 - 4.18.7

Configuration of the tubesheet			e	
Tubesheet with flange, gasketed with shell, integral with channel				
Channel type (1=Cylinder, 2=Hemispherical)			1	(1,2)
Internal operating pressure shell side		P_s	650	psi
Internal operating pressure tube side		P_t	650	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 4.18.3 (1: Ps=0, 2: Pt=0, 3:Differ.)			2	(1-3)
Shell side pressure acting (Pt=Pt,min)				
Material tubesheet	K02700-SA-516-70			
Material shell (Type abc)				
Material tubes	K01200-SA-179			
Mat. channel (Type aef)	K02700-SA-516-70			

Load temperature°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Temperat.	400	°F		°F	400	°F	400	°F
Thickness	3.625	in		in	0.085	in	0.625	in
Outside diameter	37.25	in		in	0.75	in	32.25	in
Strength	21678	psi		psi	13401	psi	21678	psi
Safety fac.	1				1		1	
Modulus of elasticity	2.781e+7	psi		psi	2.781e+7	psi	2.781e+7	psi
Allow. c_1	0	in		in	0	in	0	in
Corr.all. c_2	0.125	in		in	0	in	0	in
Poisson's ratio		v	0.3				0.3	
Therm.exp.	7.07	1E-6/°F		1E-6/°F	7.07	1E-6/°F	7.07	1E-6/°F
Yield str.	32530	psi		psi	22258	psi	32530	psi
Limit temperature	32	°F		°F	32	°F	32	°F
All.Stress	**21678**	psi	**0**	psi	**13401**	psi	**21678**	psi
Pr.+sec.st	**65035**	psi	**0**	psi	**40204**	psi	**65035**	psi
Test 20°C	**Tubesheet**		**Shell**		**Tubes**		**Channel**	
Strength	33939	psi	0	psi	23496	psi	33939	psi
Safety fac.	1				1		1	
Modulus of elasticity	2.935e+7	psi		psi	2.935e+7	psi	2.935e+7	psi
Yield str.	37710	psi		psi	26107	psi	37710	psi
Tensile str.	70343	psi		psi	47137	psi	70343	psi

Mean contact diameter tubesheet-flange (Type cf)		G_1	in
Bolt circle diameter (Type bcdef)		C	35 in

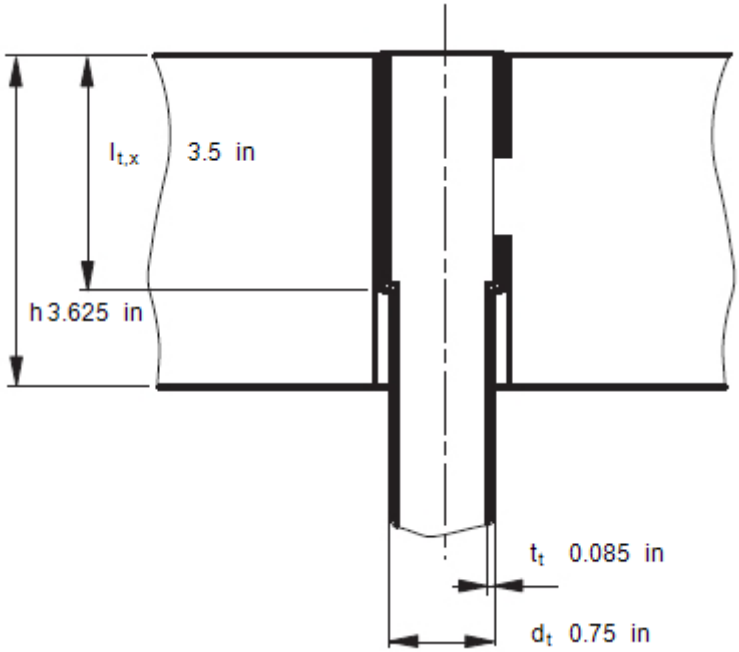
Number of bolts	n		
Bolt root diameter	d_B		in
Total bolt area	A_b		in²
Bolt material			
Strength for operation	K_s		psi
Strength at 20°C (or test)	K_{sp}		psi
Safety for operation	S_s		
Safety at 20°C (or test)	S_{sp}		
Stress enhancement factor acc. App. S	F_s	1.5	
Allowable testing stress for bolts	σ		psi
Yield stress (20°C)	Rp0,2RT		psi
Flange material			
Strength operation	K_f		psi
Strength at 20°C (or test)	K_{fp}		psi
Safety for operation	S_f		
Safety at 20°C (or test)	S_{fp}		

Gasket		**Shell Type d,e,f**		**Channel Type b,c,d**	
Contact outside diameter	G_a		in		in
Contact inside diameter	Gi		in		in
Basic seating width	b_0		in		in
Gasket factor (Table 4.16.1)	m				
Gasket seating pressure	Y		psi		psi
Diameter of gasket force	G	32.38	in		in
Results acc. 4.18.7 Step 9		**Shell**		**Channel**	
Effective seating width	b		in		in
Initial gasket force	W		lbf	**0**	lbf
Gasket operation force	W	656000	lbf	**0**	lbf
Total req. bolt root area	A_m		in²	**0**	in²
Flange thickness	h_r		in		in

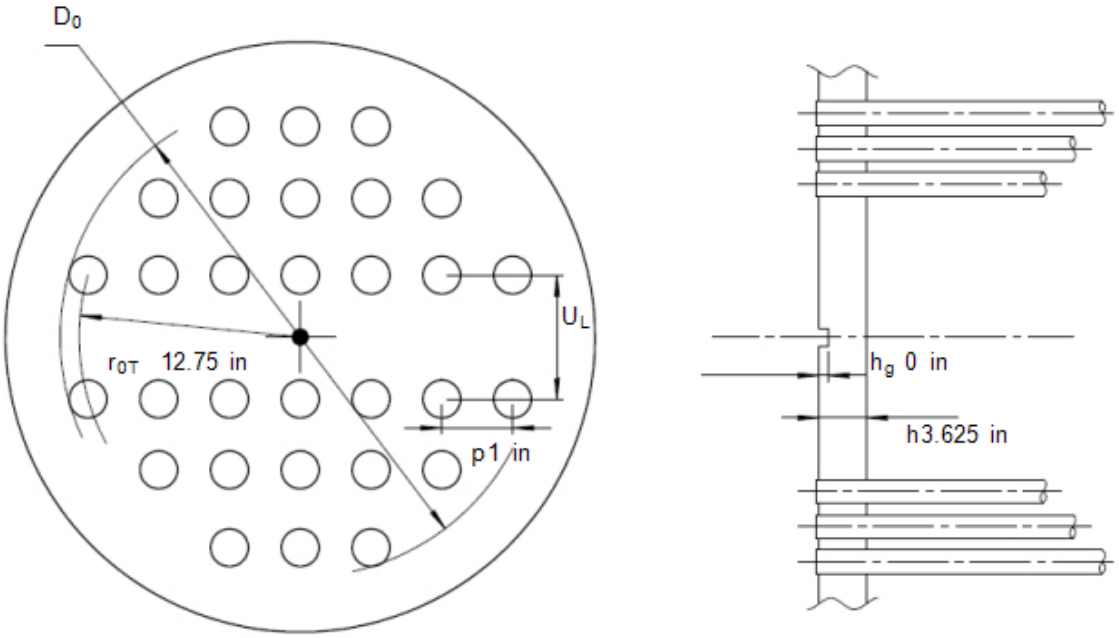
Bolt area in² :

Additional specifications for geometry and loading
Tubesheet

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



Expanded length of tube in tubesheet		$l_{t,x}$	3.5	in
Radius to outermost tube hole center	Fig. 4.18.2 a	r_{0T}	12.75	in
Perimeter of the outermost tubes	Fig. 4.18.14	C_p		in
Total area enclosed by Cp	Fig. 4.18.14	A_p		in²
Tube hole pitch (Center distance)		p	1	in



Untubed area UL1·LL1+UL2·LL2...	Fig. 4.18.3	A_L	36.09	in²
Depth of pass partition groove		h_g	0	in
Length ratio of tube expansion ltx/h		ρ	1	

Results acc. to 4.18.7

Gasket seating force = 0.5(Am+Ab)·Ksp/Ssp	Table 4.16.2	W_m	656000	lbf
Channel thickness without allowances		t_c	**0.625**	in
Shell thickness without allowances		t_s		in
Inside diameter of channel, corroded (Type ade)		D_c	**31**	in
Recommended initial tubesheet thickness	4.18.3	h_{in}	**0.9839**	in
Tubesheet thickness without allowances > hin		h	**3.5**	in

Step 1

Equivalent diameter of outer tube limit circle	D_0	**26.25**	in
Basic ligament efficiency for shear	μ	**0.25**	
Effective tubeside pass partition groove depth	h_g'	**0**	in

Step 2

Ratio Ds/D0 (Type abc) or Gs/D0 (Type def)	ρ_S	**1.234**	
Ratio Dc/D0 (Type aef) or Gc/D0 (Type bcd)	ρ_C	**1.181**	
Tubesheet rim moment due to P_s and P_t	M_{TS}	**16484**	lbf

Step 3

Effective mod. elasticity tubesheet	E*	**1.199e+7**	psi
Effective Poisson's ratio of tubesheet	v*	**0.3189**	
Effective tube pitch	p*	**1.035**	in
Effective ligament efficiency for bending	μ*	**0.377**	
Effective tube hole diameter	d*	**0.6449**	in

Step 4

Coefficient for moment of shell	ω_S	**0**	in²
Coefficient for channel pressure, Type aef	δ_c	**0.04344**	mm^3/N
Coefficient for moment of channel	ω_C	**7.037**	in²

Step 5

Diameter ratio = A/D0	K	**1.419**	
Coefficient	F	**0.9947**	

Step 6

Rim moment	M*	**26905**	lbf

Step 7

Bending moment at periphery	M_p	**6509**	lbf
Moment at the tubesheet center	M_0	**29736**	lbf

Step 8

Strength condition for the bending stress in the tubesheet:

σ = **38635** psi < **43356** psi = $2 \cdot \sigma_B$

Step 9

Strength condition for the shear stress in the tubesheet:

τ = **4875** psi ≤ **17339** psi = $MIN[0.8\sigma_B ; 0.533\ S_y]$

Strength condition satisfied

Step 10: Absolute values of stress σS in the shell and und σC in the channel

σ_S = **0** psi < **0** psi = $1.5 \cdot \sigma_{all}$

$\sigma_S = \sigma_{Sm}+\sigma_{Sb}$ = **0** psi + **0** psi

σ_C = **57335** psi < **32517** psi = $1.5 \cdot \sigma_{all}$

$\sigma_C = \sigma_{Cm}+\sigma_{Cb}$ = **0** psi + **-57335** psi

Shell length, uniform thickness > l_{Sm} = 0	or		in
Channel length, uniform thickness > l_{Cm} = 0	or	**7.923**	in

Stress too high, increase tubesheet or channel thickness 4.18.7.4 Step10

Step 11 option 3: If the strength condition of step 10 is violated, the tubesheet, shell or channel thickness can be increased acc. to option 1+2. Option 3 allows also the reduction of the elastic modulus of the shell and/or the channel.

Geometric conditions:

Please verify 0 < ro <= 1, ro=1,0000001

Equations acc. to 4.18.7 (in SI-Units)

4.18.3 If: Tubesheet thickness = 3.625 in < 0.75 in
= Tube outside diameter, the tube sheet deflection should be considered

Allowable primary and secondary stress in the shell acc. to UG-23(e):
$S_{PSs} = 3 \cdot \sigma_{all}$ (a) or 2·Yield strength (b) for operation
0 psi = 3· **0** psi or 2· psi
(b) under the condition: σ_{all} not in the creep range
T= **400** °F < °F
and: Yield strength < 0.7·Tensile strength at room temperature (20°C)

$$t_T = t_{vT} - c_{1T} - c_{2T} = 2.159\ \text{mm} - 0\ \text{mm} - 0\ \text{mm} = 2.159\ \text{mm}$$

$$h = t_{vB} - c_{1B} - c_{2B} = 92.07\ \text{mm} - 0\ \text{mm} - 3.175\ \text{mm} = 88.9\ \text{mm}$$

$$h_{in} = \frac{1}{(4 \cdot \mu)} \cdot \frac{D_0}{(0.8 \cdot \sigma_B)} \cdot \left| p_T - p_S \right| = \frac{1}{(4 \cdot 0.25)} \cdot \frac{666.8\ \text{mm}}{(0.8 \cdot 149.5\ \text{MPa})} \cdot \left| 4.482\ \text{MPa} - 4.482\ \text{MPa} \right| = 24.99\ \text{mm}$$

Step 1

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

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

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

Step 2

$$M_{TS120} = \frac{D0^2}{16} \cdot \left[((\rho_S - 1)(\rho_S{}^2 + 1) \cdot P_S) - (\rho_C - 1)(\rho C^2 + 1) \cdot P_t \right] =$$

$$\frac{(666.8\ \text{mm})^2}{16} \cdot [((1.234 - 1)((1.234)^2 + 1) \cdot 4.482\ \text{MPa}) - (1.181 - 1)((1.181)^2 + 1) \cdot 4.482\ \text{MPa}] = 73324\ \text{N}$$

Step 3

$$\rho = \frac{I_{t,x}}{h} = \frac{88.9\ \text{mm}}{88.9\ \text{mm}} = 1$$

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot A_L}{\pi \cdot D0^2}}} = \frac{25.4\ \text{mm}}{\sqrt{1 - \frac{4 \cdot 23284\ \text{mm}^2}{\pi \cdot (666.8\ \text{mm})^2}}} = 26.29\ \text{mm}$$

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

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

$$d2^* = d_T - 2 \cdot t_T \cdot \frac{E_T}{E_B} \cdot \frac{\sigma_T}{\sigma_B} \cdot \rho = 19.05\ \text{mm} - 2 \cdot 2.159\ \text{mm} \cdot \frac{191733\ \text{MPa}}{191733\ \text{MPa}} \cdot \frac{92.4\ \text{MPa}}{149.5\ \text{MPa}} \cdot 1 = d2^*$$

$$\mu^* = \frac{(p^* - d^*)}{d^*} = \frac{(26.29\ \text{mm} - 16.38\ \text{mm})}{16.38\ \text{mm}} = 0.377$$

Step 4

Type abc:	β_S		1/ft	k_S		lbf	λ_S	**0**	psi
Type aef:	β_C	**4.907**	1/ft	k_C	**508427**	lbf	λ_C	**7774348**	psi

Step 5

$$F=\frac{(1-\nu^*)}{E^*}\cdot(\lambda_S+\lambda_C+E^*\cdot\ln(K))=\frac{(1-0.3189)}{82657\ \text{MPa}}\cdot(0\ \text{MPa}+53603\ \text{MPa}+191733\ \text{MPa}\cdot\ln(1.419))=0.9947$$

Step 6

$$M^*=M_{TS}+\omega_C\cdot P_c-\omega_S\cdot P_s+M_{add}=73324\ \text{N}+4540\ \text{mm}^2\cdot 0\ \text{MPa}-0\ \text{mm}^2\cdot 4.482\ \text{MPa}+46353\ \text{N}=119677\ \text{N}$$

M_{add} = (C-Gs)*Wm/(2* PI *D0) = **10421** lbf

4.18.7.4 acc. 4.18.7.5

$$Mfd^*=M_{TS}+M_{add}=73324\ \text{N}+46353\ \text{N}=119677\ \text{N}$$

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

σ			**or**	**σ acc. 4.18.7.5**		**< 2· σ_B**		
σ =	**38635**	psi	or	**46213**	psi	< 2·	**21678**	psi

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

τ			**or**	**τ acc. 4.18.7.5**		**≤ MIN[0.8σ_B ; 0.533 S_y]**		
τ =	**4875**	psi	or	**4875**	psi	≤	**17339**	psi

Strength condition satisfied

If the strength condition in step 8 or 9 is violated, the tubesheet thickness must be increased.
Actual thickness 3.625 in

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

in MPa:	**σ_m**		**σ_b**			**< 1.5 · σ_{all}**		**or**	**S_{PS} *)**
$\sigma_S=\sigma_{Sm}+\sigma_{Sb}$ =	**0**	+	**0**	=	**0**	< 1.5·	**0**	or	**0**
$\sigma_C=\sigma_{Cm}+\sigma_{Cb}$ =	**0**	+	**-395.3**	=	**395.3**	< 1.5·	**149.5**	or	**448.4**

*) Simply supported (N) acc. 4.18.7.5

Stress too high, increase tubesheet or channel thickness 4.18.7.4 Step10

Step 11: The modulus of elasticity is reduced: N (Y=Yes,N=No)

Modulus of elasticity	elastic	Option 3
Shell	psi	psi
Channel	**2.781e+7** psi	**2.781e+7** psi

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

σ_S = **0** psi ≤ **0** psi = S_{PSs}

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

Analogously for the channel:

σ_C = **57335** psi ≤ **65035** psi = S_{PSc}