Configuration d: Tubesheet Gasketed With Shell and Channel
Data Summary

		differential design pressure	---	MPa
P_s	=	shell side design pressure		
$P_{sd,max}$	=	maximum shell side design pressure	0.000	MPa
$P_{sd,min}$	=	minimum shell side design pressure	-0.104	MPa
P_t	=	tube side design pressure		
$P_{td,max}$	=	maximum tube side design pressure	0.931	MPa
$P_{td,min}$	=	minimum tube side design pressure	0.000	MPa
T	=	tubesheet design temperature	148.900	°C
		tubesheet material	A285GRC	
S	=	allowable stress for tubesheet material at T	108.250	MPa
E	=	modulus of elasticity for tubesheet material at T	195121.600	MPa
		tube material	B111C44300	
S_{tT}	=	allowable stress for tube material at T	68.948	MPa
E_{tT}	=	modulus of elasticity for tube material at T	106179.300	MPa
c_s	=	tubesheet corrosion allowance on the shell side	0.000	mm
c_t	=	tubesheet corrosion allowance on the tube side	3.175	mm
h_g	=	tube side pass partition groove depth	0.000	mm
d_t	=	nominal outside diameter of tubes	15.875	mm
t_t	=	nominal tube wall thickness	1.651	mm
p	=	tube pitch	19.050	mm
		tube pattern	30	°
r_o	=	radius to outermost tube hole center	205.590	mm
C_p	=	perimeter of the tube layout measured stepwise in increments of one tube pitch from the center-to-center of the outermost tubes	1341.633	mm
A_p	=	total area enclosed by C_p	143237.800	mm^2
A_L	=	total area of untubed lanes	18968.000	mm^2
ℓ_{tx}	=	expanded length of tube in tubesheet	36.000	mm
A	=	outside diameter of tubesheet	508.000	mm
G_s	=	diameter of shell gasket load reaction	482.600	mm
W_s	=	shell flange design bolt load for gasket seating condition	653889.000	N
W_{m1s}	=	shell flange design bolt load for operating condition	653889.000	N
G_c	=	diameter of channel gasket load reaction	482.600	mm
W_c	=	channel flange design bolt load for gasket seating condition	720612.000	N
W_{m1c}	=	channel flange design bolt load for operating condition	720612.000	N
$h_{(nom)}$	=	nominal thickness of tubesheet	35.687	mm
$h_{r(nom)}$	=	nominal thickness of tubesheet extension	13.168	mm

Minimum required thickness of tubesheet extension, h_r from UHX-9.5.

Summary Table for Calculation of h_r					
		Design Loading Case			
		1	2	3	4
Ps	MPa	-0.104	0.000	0.000	-0.104
Pt	MPa	0.931	0.000	0.931	0.000
D_E	mm	482.600	482.600	482.600	482.600
h_r	mm	1.442	0.000	1.297	0.145

Note: $D_E = \text{MAX}[G_s, G_c]$ for conservative evaluation.

The design of the tubesheet extension is acceptable.

Calculation Procedure

a) STEP 1 - Calculate D_o, μ, p^*, and h_g' from UHX-11.5.1.

Summary Table for STEP 1					
		Design Loading Case			
		1	2	3	4
P_s	MPa	-0.104	0.000	0.000	-0.104
P_t	MPa	0.931	0.000	0.931	0.000
D_o	mm	427.055	427.055	427.055	427.055
μ		0.167	0.167	0.167	0.167
p^*	mm	20.452	20.452	20.452	20.452
h_g'	mm	0.000	0.000	0.000	0.000

b) STEP 2- Calculate ρ_s, ρ_c, and M_{TS} for configuration d.

Summary Table for STEP 2					
		Design Loading Case			
		1	2	3	4
ρ_s		1.130	1.130	1.130	1.130
ρ_c		1.130	1.130	1.130	1.130
M_{TS}	N	-3493.986	0.000	-3142.899	-351.087

c) STEP 3 - Assume a value for the tubesheet thickness, h, and calculate ρ, d^*, μ^*, and h/p. Determine E^*/E and ν^* from UHX-11.5.2 and calculate E^*.

Summary Table for STEP 3					
		Design Loading Case			
		1	2	3	4
h	mm	32.512	32.512	32.512	32.512
ρ		1.000	1.000	1.000	1.000
d^*	mm	14.731	14.731	14.731	14.731
μ^*		0.280	0.280	0.280	0.280
h/p		1.707	1.707	1.707	1.707
E^*/E		0.265	0.265	0.265	0.265
ν^*		0.358	0.358	0.358	0.358
E^*	MPa	51732.781	51732.781	51732.781	51732.781

d) STEP 4 - For configuration d, skip STEP 4 and proceed to STEP 5.

e) STEP 5 - Calculate K and F for configuration d.

Summary Table for STEP 5				
	Design Loading Case			
	1	2	3	4
K	1.190	1.190	1.190	1.190
F	0.421	0.421	0.421	0.421

f) STEP 6 - Calculate M^* for configuration d.

Summary Table for STEP 6					
		Design Loading Case			
		1	2	3	4
W^*	N	720612.000	653889.000	720612.000	720612.000
M^*	N	-3493.986	0.000	-3142.899	-351.087

g) STEP 7 - Calculate M_p, M_o, and M.

Summary Table for STEP 7					
		Design Loading Case			
		1	2	3	4
M_p	N	-713.405	0.000	-641.720	-71.685
M_o	N	-10616.280	0.000	-9549.520	-1066.756
M	N	10616.280	0.000	9549.520	1066.756

h) STEP 8 - Calculate σ and check the acceptance criterion.

Summary Table for STEP 8					
		Design Loading Case			
		1	2	3	4
σ	MPa	215.402	0.000	193.758	21.644
$2S$	MPa	216.500	216.500	216.500	216.500

MAX$[\sigma] \leq 2S$; The assumed value for the tubesheet thickness, h is acceptable.

i) STEP 9 - Calculate τ and check the acceptance criterion.

Summary Table for STEP 9					
		Design Loading Case			
		1	2	3	4
τ	MPa	20.393	0.000	18.343	2.049
$0.8S$	MPa	86.600	86.600	86.600	86.600

MAX$[\tau] \leq 0.8S$; The assumed value for the tubesheet thickness, h is acceptable.

Configuration d: Tubesheet Gasketed With Shell and Channel

Data Summary

		differential design pressure	2.069	MPa
P_s	=	shell side design pressure		
$P_{sd,max}$	=	maximum shell side design pressure	2.586	MPa
$P_{sd,min}$	=	minimum shell side design pressure	0.000	MPa
P_t	=	tube side design pressure		
$P_{td,max}$	=	maximum tube side design pressure	0.517	MPa
$P_{td,min}$	=	minimum tube side design pressure	0.000	MPa
T	=	tubesheet design temperature	260.000	°C
		tubesheet material	SA-516Gr70	
S	=	allowable stress for tubesheet material at T	137.900	MPa
E	=	modulus of elasticity for tubesheet material at T	186848.000	MPa
		tube material	SB111C70600	
S_{tT}	=	allowable stress for tube material at T	55.158	MPa
E_{tT}	=	modulus of elasticity for tube material at T	114453.000	MPa
c_s	=	tubesheet corrosion allowance on the shell side	0.000	mm
c_t	=	tubesheet corrosion allowance on the tube side	3.200	mm
h_g	=	tube side pass partition groove depth	4.763	mm
d_t	=	nominal outside diameter of tubes	19.050	mm
t_t	=	nominal tube wall thickness	1.245	mm
p	=	tube pitch	23.813	mm
		tube pattern	30	°
r_o	=	radius to outermost tube hole center	520.700	mm
C_p	=	perimeter of the tube layout measured stepwise in increments of one tube pitch from the center-to-center of the outermost tubes	3331.502	mm
A_p	=	total area enclosed by C_p	883222.930	mm^2
A_L	=	total area of untubed lanes	60581.000	mm^2
ℓ_{tx}	=	expanded length of tube in tubesheet	55.910	mm
A	=	outside diameter of tubesheet	1241.600	mm
G_s	=	diameter of shell gasket load reaction	1104.900	mm
W_s	=	shell flange design bolt load for gasket seating condition	3002550.000	N
W_{m1s}	=	shell flange design bolt load for operating condition	3002550.000	N
G_c	=	diameter of channel gasket load reaction	1140.000	mm
W_c	=	channel flange design bolt load for gasket seating condition	2597762.000	N
W_{m1c}	=	channel flange design bolt load for operating condition	2597762.000	N
$h_{(nom)}$	=	nominal thickness of tubesheet	108.610	mm
$h_{r(nom)}$	=	nominal thickness of tubesheet extension	86.610	mm

Minimum required thickness of tubesheet extension, h_r from UHX-9.5.

Summary Table for Calculation of h_r					
		Design Loading Case			
		1	2	3	4
Ps	MPa	---	---	2.586	---
Pt	MPa	---	---	0.517	---
D_E	mm	---	---	1140.000	---
h_r	mm	---	---	5.345	---

Note: $D_E = \text{MAX}[G_s, G_c]$ for conservative evaluation.

The design of the tubesheet extension is acceptable.

Calculation Procedure

a) STEP 1 - Calculate D_o, μ, p^*, and $h_g^{'}$ from UHX-11.5.1.

Summary Table for STEP 1				
	Design Loading Case			
	1	2	3	4
P_s MPa	---	---	2.586	---
P_t MPa	---	---	0.517	---
D_o mm	---	---	1060.450	---
μ	---	---	0.200	---
p^* mm	---	---	24.674	---
$h_g^{'}$ mm	---	---	1.563	---

b) STEP 2- Calculate ρ_s, ρ_c, and M_{TS} for configuration d.

Summary Table for STEP 2				
	Design Loading Case			
	1	2	3	4
ρ_s	---	---	1.042	---
ρ_c	---	---	1.075	---
M_{TS} N	---	---	10013.102	---

c) STEP 3 - Assume a value for the tubesheet thickness, h, and calculate ρ, d^*, μ^*, and h/p. Determine E^*/E and ν^* from UHX-11.5.2 and calculate E^*.

Summary Table for STEP 3				
	Design Loading Case			
	1	2	3	4
h mm	---	---	105.410	---
ρ	---	---	0.500	---
d^* mm	---	---	18.745	---
μ^*	---	---	0.240	---
h/p	---	---	4.427	---
E^*/E	---	---	0.204	---
ν^*	---	---	0.407	---
E^* MPa	---	---	38193.441	---

d) STEP 4 - For configuration d, skip STEP 4 and proceed to STEP 5.

e) STEP 5 - Calculate K and F for configuration d.

Summary Table for STEP 5				
	Design Loading Case			
	1	2	3	4
K	---	---	1.171	---
F	---	---	0.458	---

f) STEP 6 - Calculate M^* for configuration d.

Summary Table for STEP 6				
	Design Loading Case			
	1	2	3	4
W^* N	---	---	3002550.000	---
M^* N	---	---	25830.210	---

g) STEP 7 - Calculate M_p, M_o, and M.

Summary Table for STEP 7					
		Design Loading Case			
		1	2	3	4
M_p	N	---	---	-5107.065	---
M_o	N	---	---	118747.900	---
M	N	---	---	118747.900	---

h) STEP 8 - Calculate σ and check the acceptance criterion.

Summary Table for STEP 8					
		Design Loading Case			
		1	2	3	4
σ	MPa	---	---	274.934	---
$2S$	MPa	---	---	275.800	---

MAX$[\sigma] \leq 2S$; The assumed value for the tubesheet thickness, h is acceptable.

i) STEP 9 - Calculate τ and check the acceptance criterion.

Summary Table for STEP 9					
		Design Loading Case			
		1	2	3	4
τ	MPa	---	---	26.016	---
$0.8S$	MPa	---	---	110.320	---

MAX$[\tau] \leq 0.8S$; The assumed value for the tubesheet thickness, h is acceptable.

Configuration e: Tubesheet Gasketed With Shell and Integral With Channel, Extended as a Flange
Data Summary

		differential design pressure	---	MPa
P_s	=	shell side design pressure		
$P_{sd,max}$	=	maximum shell side design pressure	4.482	MPa
$P_{sd,min}$	=	minimum shell side design pressure	0.000	MPa
P_t	=	tube side design pressure		
$P_{td,max}$	=	maximum tube side design pressure	4.482	MPa
$P_{td,min}$	=	minimum tube side design pressure	0.000	MPa
T	=	tubesheet design temperature	204.500	°C
T_c	=	channel design temperature	204.500	°C
		tubesheet material	A516GR70	
S	=	allowable stress for tubesheet material at T	137.890	MPa
S_a	=	allowable stress for the material of the tubesheet extension at ambient temperature	137.890	MPa
E	=	modulus of elasticity for tubesheet material at T	190985.000	MPa
		tube material	A179	
S_{tT}	=	allowable stress for tube material at T	92.380	MPa
E_{tT}	=	modulus of elasticity for tube material at T	190985.000	MPa
		channel material	A516GR70	
ν_c	=	Poisson's ratio of channel material	0.300	
S_c	=	allowable stress for channel material at T_c	137.890	MPa
E_c	=	modulus of elasticity for channel material at T_c	190985.000	MPa
$S_{y,c}$	=	yield strength for channel material at T_c	224.080	MPa
$S_{PS,c}$	=	allowable primary plus secondary stress for channel material at T_c	448.160	MPa
c_s	=	tubesheet corrosion allowance on the shell side	0.000	mm
c_t	=	tubesheet corrosion allowance on the tube side	3.200	mm
h_g	=	tube side pass partition groove depth	0.000	mm
$c_{(ch)}$	=	channel corrosion allowance	0.000	mm
d_t	=	nominal outside diameter of tubes	19.050	mm
t_t	=	nominal tube wall thickness	2.159	mm
p	=	tube pitch	25.400	mm
		tube pattern	90	°
r_o	=	radius to outermost tube hole center	323.850	mm
C_p	=	perimeter of the tube layout measured stepwise in increments of one tube pitch from the center-to-center of the outermost tubes	2094.657	mm
A_p	=	total area enclosed by C_p	349153.100	mm^2
A_L	=	total area of untubed lanes	23290.000	mm^2
ℓ_{tx}	=	expanded length of tube in tubesheet	92.100	mm
A	=	outside diameter of tubesheet	946.150	mm
G_s	=	diameter of shell gasket load reaction	822.330	mm
W_s	=	shell flange design bolt load for gasket seating condition	2918034.000	N
W_{m1s}	=	shell flange design bolt load for operating condition	2918034.000	N
$h_{(nom)}$	=	nominal thickness of tubesheet	92.100	mm
C	=	bolt circle diameter	889.000	mm
$h_{r(nom)}$	=	nominal thickness of tubesheet extension	81.100	mm
D_c	=	inside channel diameter	787.400	mm
$t_{c(nom)}$	=	nominal thickness of channel	15.900	mm

U-TUBE TUBESHEET According to UHX of ASME BPVC Sec. VIII Div. 1, 2013 Edition

Minimum required thickness of tubesheet extension, h_r from UHX-9.5.

Summary Table for Calculation of h_r					
		Design Loading Case			
		1	2	3	4
W	N	2918034.000	2918034.000	2918034.000	---
$Wm1$	N	0.000	2918034.000	2918034.000	---
G	mm	822.330	822.330	822.330	---
h_G	mm	33.335	33.335	33.335	---
h_r	mm	40.372	40.372	40.372	---

The design of the tubesheet extension is acceptable.

Calculation Procedure

a) STEP 1 - Calculate D_o, μ, p^*, and $h_g^{'}$ from UHX-11.5.1.

Summary Table for STEP 1					
		Design Loading Case			
		1	2	3	4
P_s	MPa	0.000	4.482	4.482	---
P_t	MPa	4.482	0.000	4.482	---
D_o	mm	666.750	666.750	666.750	---
μ		0.250	0.250	0.250	---
p^*	mm	26.292	26.292	26.292	---
$h_g^{'}$	mm	0.000	0.000	0.000	---

b) STEP 2- Calculate ρ_s, ρ_c, and M_{TS} for configuration e.

Summary Table for STEP 2					
		Design Loading Case			
		1	2	3	4
ρ_s		1.233	1.233	1.233	---
ρ_c		1.181	1.181	1.181	---
M_{TS}	N	-53961.550	73259.523	19297.974	---

c) STEP 3 - Assume a value for the tubesheet thickness, h, and calculate ρ, d^*, μ^*, and h/p. Determine E^*/E and ν^* from UHX-11.5.2 and calculate E^*.

Summary Table for STEP 3					
		Design Loading Case			
		1	2	3	4
h	mm	88.900	88.900	88.900	---
ρ		1.000	1.000	1.000	---
d^*	mm	16.157	16.157	16.157	---
μ^*		0.385	0.385	0.385	---
h/p		3.500	3.500	3.500	---
E^*/E		0.441	0.441	0.441	---
ν^*		0.318	0.318	0.318	---
E^*	MPa	84282.890	84282.890	84282.890	---

d) STEP 4 - For configuration e, calculate β_c, k_c, λ_c, δ_c, and ω_c for the channel.

Summary Table for STEP 4					
		Design Loading Case			
		1	2	3	4
β_c	mm^{-1}	0.016	0.016	0.016	---
k_c	N	2261602.000	2261602.000	2261602.000	---
λ_c	MPa	52501.150	52501.150	52501.150	---
δ_c	mm^3/N	0.043	0.043	0.043	---
ω_c	mm^2	4529.154	4529.154	4529.154	---

e) STEP 5 - Calculate K and F for configuration e.

Summary Table for STEP 5					
		Design Loading Case			
		1	2	3	4
K		1.419	1.419	1.419	---
F		0.966	0.966	0.966	---

f) STEP 6 - Calculate M^* for configuration e.

Summary Table for STEP 6					
		Design Loading Case			
		1	2	3	4
W^*	N	0.000	2918034.000	2918034.000	---
M^*	N	-33661.880	119698.000	86036.101	---

g) STEP 7 - Calculate M_p, M_o, and M.

Summary Table for STEP 7					
		Design Loading Case			
		1	2	3	4
M_p	N	13468.081	30297.760	43765.840	---
M_o	N	-89827.680	133593.510	43765.840	---
M	N	89827.680	133593.510	43765.840	---

h) STEP 8 - Calculate σ and check the acceptance criterion.

Summary Table for STEP 8					
		Design Loading Case			
		1	2	3	4
σ	MPa	176.914	263.110	86.196	---
$2S$	MPa	275.780	275.780	275.780	---

MAX$[\sigma] \leq 2S$; The assumed value for the tubesheet thickness, h is acceptable.

i) STEP 9 - Calculate τ and check the acceptance criterion.

Summary Table for STEP 9					
		Design Loading Case			
		1	2	3	4
τ	MPa	33.615	33.615	0.000	---
$0.8S$	MPa	110.312	110.312	110.312	---

MAX$[\tau] \leq 0.8S$; The assumed value for the tubesheet thickness, h is acceptable.

j) STEP 10 - For configuration e, calculate $\sigma_{c,m}$, $\sigma_{c,b}$, and σ_c for the channel, and check the acceptance criterion.

Summary Table for STEP 10					
		Design Loading Case			
		1	2	3	4
$\sigma_{c,m}$	MPa	54.391	0.000	54.391	---
$\sigma_{c,b}$	MPa	374.872	-392.627	-17.755	---
σ_c	MPa	429.263	392.627	72.146	---
$1.5S_c$	MPa	206.835	206.835	206.835	---
$S_{PS,c}$	MPa	448.160	448.160	448.160	---
Procedure		next step	next step	complete	---

If $\sigma_c \leq 1.5S_c$, the channel design is acceptable and the calculation procedure is complete. Otherwise, proceed to STEP 11.

k) STEP 11 - Since $\sigma_c \leq S_{PS,c}$ for all loading cases, option 3 is used. Calculate E_c^* for each loading case where $\sigma > 1.5S_c$. Recalculate k_c, λ_c given in STEP 4 using the applicable reduced effective modulus E_c. Recalculate F given in STEP 5. Recalculate M_p, M_o, and M given in STEP 7. Recalcurate σ given in STEP 8.

Summary Table for STEP 11					
		Design Loading Case			
		1	2	3	4
E_c^*	MPa	132571.320	138618.500	---	---
k_c	N	1569880.200	1641489.000	---	---
λ_c	MPa	0.063	0.060	---	---
F		0.836	0.849	---	---
M_p	N	10013.940	36128.851	---	---
M_o	N	-93281.820	139424.600	---	---
M	N	93281.820	139424.600	---	---
σ	MPa	183.717	274.595	---	---
$2S$	MPa	275.780	275.780	---	---

MAX$[\sigma] \leq 2S$; The assumed value for the tubesheet thickness, h is acceptable.