MECHANICAL DESIGN CALCULATION

IN ACCORDANCE WITH TECHNICAL RULES FOR PRESSURE VESSELS

AD 2000: Ausgabe 11-2007

CUSTOMER	: MAVEG INDUSTRIEAUSRÜSTUNGEN
CUSTOMER Ref. №	: 50-014/09-0183k
PLANT	: THE BLOCK OF ISOMERISATION - 600
PROJECT	: MAVEG C5/C6
EQUIPMENT NAME	: DEISOHEXANIZER REBOILER
ITEM NUMBER	: E-610
ENGINEERED BY	: HITARD ENGINEERING
HITARD Ref. №	: 10H130-1
LURGI Ref. №	: 1.04962
CALCULATION №	: A4-E-610-CAL
DRAWING №	: 04962-SE-00089

0	29.07.2010.	FOR APPROVAL	HITARD	H.E.	
Rev.	Date	Description	Prepr'd	Check'd	Approv'd

TABULATION OF REVISED PAGES

SHEET	Rev. 0	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 5	Rev. 6	Rev. 7	SHEET	Rev. 0	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 5	Rev. 6	Rev. 7
1	×								51	×							
2	×								52	×							
3	×								53	×							
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48	×								98	×							
49	×								99	×							
50	×								100	×							

TABULATION OF REVISED PAGES

SHEET	Rev. 0	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 5	Rev. 6	Rev. 7	SHEET	Rev. 0	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 5	Rev. 6	Rev. 7
101	×								151								
102	×								152								
103	×								153								
104	×								154								
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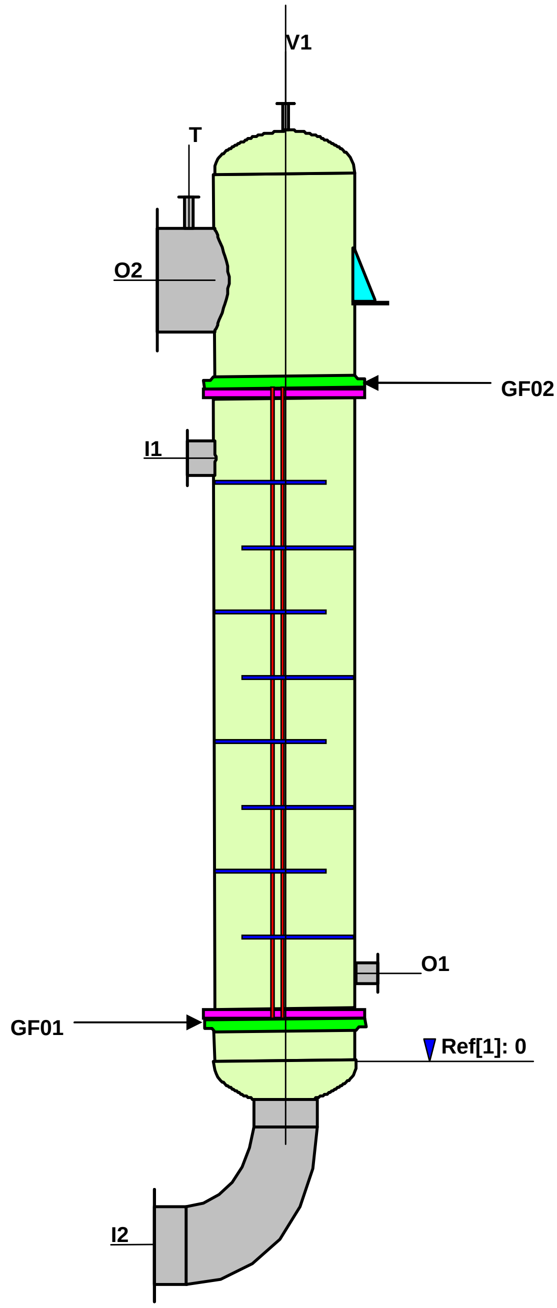
150									200								



For definitions i.e. Pos. Numbers see Page Nr. 8

BEM

TEMA TYPE

Engineered by :	Hitard Engineering	Description :	Deisohexanizer Reboiler
Customer :	Maveg Industrieausrüstungen	Drawing No. :	04962-SE-00089
Project :	MAVEG C5/C6	Revision :	0

Table of Contents

Input data list

Design Parameters.

Design Code :	AD-MERKBLAETTER 2000 (11-2007)	Karman Effects Prevented by 3 Helicoidal Plates at 120° :	no
Nozzle Local Load Design Method :	WRC 107 (2002-10)	Design length for vertical vessels :	500 mm
Nozzle flanges in acc. with :	ASME B16.5-2003/B16.47-1990	Specific Gravity of base material :	8
Nozzle necks in acc. with :	NF A 49	Design and optimize :	yes
Apply UG 45 :	no	Design check :	no
Apply UG 36(c)(3)	no	MAWP requested :	no
Apply PD A.3.6 :	no	With vacuum stiffeners :	no
Apply ASME - UG 23 (d) :	no	Associated shell as stiffening :	yes
Apply UBC 1612.3.2 (33%)	no	Support rings as stiffening :	no
Apply DIN 18800 part 4	no	Min. distance between stiffeners :	300 mm
Material DataBase :	C:\Program Files\...\Material.emdm	Gas / Vapor :	yes

Considered :	Piping	Platforms	Ladders	FP	Insulation	Trays	Scaffolding
Lifting	/	/	/	/	/	/	/
Erection	M+W	M+W	M+W	/	/	/	/
Service	M+W	M+W	M+W	M+W	M+W	M	/
Shut-down	M+W	M+W	M+W	M+W	M+W	M	/
Test	M+W	M+W	M+W	/	/	/	/
M means that the weight of accessories is considered for the case.				W means that the effect of wind load on accessories is considered			

Load case	Lifting	Erection	Service	Shut-down	Test	Raw weight	Corroded weight
	yes	yes	yes	yes	yes	yes	no

Default Values.

Rounding up Dist. Flange / Axis :	5 mm	Mini. Dist. Insulation / Flange :	75 mm	
OTL extension for welded tubes :	12 mm	Safety factor for flanges operation/test :	1	1
Rule limiting available area in opening reinforcement f(T) :			1	
Friction Factor for Bolt Torque - Thread / Nut supporting surface :			0.12	0.12

Geometry Definition.

No.	Type	Tag	Designation	Thk. (*) (mm)	Corr. (mm)	Tol. (mm)	Temp. (°C)
01	Korbbogen Type Head	TS01	Channel head	20.000	3.0	0.0	167.0
02	Shell	TS02	Channel barrel	16.000	3.0	0.0	167.0
03	Body Flange	GF01	Channel girth flange	72.0	3.0	1.6	167.0
04							
05	Tubesheet	TT01	Stationary Tubesheet	80.000	3 / 3	1.6	400.0
06	Shell	SS01	Shell barrel	16.000	3.0	0.0	400.0
07	Tubesheet	TT02	Stationary Tubesheet	80.000	3 / 3	1.6	400.0
08							
09	Body Flange	GF02	Channel girth flange	72.0	3.0	1.6	167.0
10	Shell	TS03	Channel barrel	16.000	3.0	0.0	167.0
11	Korbbogen Type Head	TS04	Channel head	16.000	3.0	0.0	167.0

(*) minimum input thickness.

Nozzle Definition.

No.	Tag	Location Loc. (mm)	Ori. (°)	Inc. (°)	Ecc. (mm)	Designation	Nozzle Type
1	I1	4,654.0	270	0.00	0.00	Shell Side Inlet	WN-RF
2	O1	684.0	90	0.00	0.00	Shell Side Outlet	WN-RF
3	O2	6,034.0	270	0.00	0.00	Tube Side Outlet	WN-RF
4	I2	-1,426.0	270	0.00	0.00	Tube Side Inlet	WN-RF
5	V1	7,380.0	0	0.00	0.00	Vent	WN-RF
6	T	300.0	0	0.00	0.00	Thermowell	LWN-RF

Flange Definition.

Flange No. 1 GF01 Channel girth flange

Body Flange : Integral with hub		Short hub and optimisation of the Gasket Circle Reaction	
Reverse : no	With studs : no	Cylindrical hub : no	Flange one piece shell : no

Bolting: ISO, Pitch 3 mm when > M24; Root Area	Confined Smooth face female 5 mm
Cylindrical nuts : no	Tensioner : no

Gasket : Grooved Metal + Graphite Layer	Inside the Bolt Circle		
DIN 2505	k_0 (mm)= k_1 (mm) = 1.1*BD	$k_0.K_D$ (N/mm) = 20*BD $K_{D\vartheta}$ = 0 MPa	K_D = 0 MPa
DIN 28090	σ_{VU} = 0 MPa	σ_{VO} = 0 MPa	σ_{BO} = 0 MPa

Flange No. 2 GF02 Channel girth flange

Body Flange : Integral with hub		Short hub and optimisation of the Gasket Circle Reaction	
Reverse : no	With studs : no	Cylindrical hub : no	Flange one piece shell : no

Bolting: ISO, Pitch 3 mm when > M24; Root Area	Confined Smooth face female 5 mm
Cylindrical nuts : no	Tensioner : no

Gasket : Grooved Metal + Graphite Layer	Inside the Bolt Circle		
DIN 2505	k_0 (mm)= k_1 (mm) = 1.1*BD	$k_0.K_D$ (N/mm) = 20*BD $K_{D\vartheta}$ = 0 MPa	K_D = 0 MPa
DIN 28090	σ_{VU} = 0 MPa	σ_{VO} = 0 MPa	σ_{BO} = 0 MPa

Tubesheet Definition.

Design Code: EN 13445:2002 V26 (2007-04)	Differential design pressure: no

Design case excluding Test

No.	Operating Condition	Shellside		Tubeside	
		Pressure (MPa)	Temperature. (°C)	Pressure (MPa)	Temperature (°C)
1	normal	0.84	177	0.28	136
2	normal	-0.1	177	0.28	136
3	normal	0.84	177	-0.1	167
4	normal	0.1	204	0.28	163
	abnormal	0	20	0	20

List of Materials.

Tubeside

Channel shell :	P355NL1	EN 10028-3
Flange :	P355NH	EN 10222-4
Studbolts :	25CrMo4	EN 10269

Shellside

Shell :	P355NL1	EN 10028-3
Saddles, brackets :	P355NL1	EN 10028-3

Nozzles

Nozzle neck, tubeside :	P355NL1	EN 10216-3
Reinforcing pads, tubeside :	P355NL1	EN 10028-3
Nozzle flanges, tubeside :	P355NH	EN 10222-4
Nozzle necks, shellside :	P355NL1	EN 10216-3
Reinforcing pads, shellside :	P355NL1	EN 10028-3
Nozzle flanges, shellside :	P355NH	EN 10222-4

Bundle

Tubesheets :	P355NH	EN 10222-4
Tubes :	P355NL1	EN 10216-3
Baffles :	P265GH	EN 10028-2
Tie-rods :	S235JRG2	EN 10027
Spacers :	S235JR	EN 10027

Gaskets

Grooved Metal + Graphite Layer :	1.4571 + Graphite
The calculations settings factors :	k_1 = 1.1*BD, $k_0.K_D$ = 20*BD

Accessories

Lifting lugs and trunnions :	P355NL1	EN 10028-3
Test flanges :	A105N	

25CrMo4 EN10269 (Bolting, Carbon Steel, November 1999)

1.7218 Specific gravity : 7.85 Elongation : 18 % Poisson Factor : 0.3 Reference Temp. : -50 °C

Modulus of elasticity

°C	*-100*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*
MPa×10^3	207	201	196	193	189	187	184	178	170	160

Coefficients of thermal expansion

°C	*-100*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*	*500*	*550*
mm/mm×10^{-6}	9.9	10.9	11.5	11.9	12.3	12.6	12.9	13.3	13.6	13.9	14.2	14.4

Tensile strength — Limits apply on diameter (mm).

100	°C	*20*
	MPa	600
150	°C	*20*
	MPa	600

Yield strength 0.2% — Limits apply on diameter (mm).

100	°C	*20*	*200*	*250*	*300*	*350*	*400*	*450*	*500*
	MPa	440	412	392	363	333	304	275	235
150	°C	*20*	*200*	*250*	*300*	*350*	*400*	*450*	*500*
	MPa	420	382	372	344	324	294	265	226

P355NL1 EN10028-3 (Plate, Carbon Steel, May 2003)

1.0565 Specific gravity : 7.85 Elongation : 22 % Poisson Factor : 0.3 Reference Temp. : -40 °C

Chemical composition (%)

C	*Mn*	*Ni*
0.18	1.5	0.50

Modulus of elasticity

°C	*-100*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*
MPa×10^3	207	201	196	193	189	187	184	178	170	160

Coefficients of thermal expansion

°C	*-100*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*	*500*	*550*
mm/mm×10^{-6}	9.9	10.9	11.5	11.9	12.3	12.6	12.9	13.3	13.6	13.9	14.2	14.4

Tensile strength — Limits apply on thickness (mm).

16	°C	*20*
	MPa	490
40	°C	*20*
	MPa	490
60	°C	*20*
	MPa	490
100	°C	*20*
	MPa	470
150	°C	*20*
	MPa	460
250	°C	*20*
	MPa	450

Yield strength 0.2% — Limits apply on thickness (mm).

16	°C	*20*	*50*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	345	343	323	299	275	252	232	214	202
40	°C	*20*	*50*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	335	334	314	291	267	245	225	208	196
60	°C	*20*	*50*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	325	324	305	282	259	238	219	202	190
100	°C	*20*	*50*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	305	305	287	265	244	224	206	190	179
150	°C	*20*	*50*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	295	295	277	257	236	216	199	184	173
250	°C	*20*	*50*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	285	285	268	249	228	209	192	178	167

P355NL1 EN10216-3 (Seamless pipe, Carbon Steel, December 2002)

1.0565 Specific gravity : 7.85 Elongation : 20 % Poisson Factor : 0.3 Reference Temp. : -40 °C

Chemical composition (%)

C	*Si*	*Mn*	*P*	*S*	*Al*	*Cr*	*Cu*	*Mo*	*N*	*Nb*	*Ni*	*Ti*	*V*
-0.20	-0.50	0.90-1.70	-0.025	-0.020	+0.020	-0.30	-0.30	-0.08	-0.020	-0.05	-0.05	-0.040	-0.10

Modulus of elasticity

°C	*-100*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*
MPa×10^3	207	201	196	193	189	187	184	178	170	160

Coefficients of thermal expansion

°C	*-100*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*	*500*	*550*
mm/mm×10^{-6}	9.9	10.9	11.5	11.9	12.3	12.6	12.9	13.3	13.6	13.9	14.2	14.4

Tensile strength — Limits apply on thickness (mm).

20	*°C*	*20*
	MPa	490
40	*°C*	*20*
	MPa	490
50	*°C*	*20*
	MPa	490
65	*°C*	*20*
	MPa	450
80	*°C*	*20*
	MPa	450
100	*°C*	*20*
	MPa	450

Yield strength 0.2% — Limits apply on thickness (mm).

20	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	355	304	284	255	235	216	196	167
40	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	345	294	275	255	235	216	196	167
50	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	335	294	275	255	235	216	196	167
65	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	325	284	265	245	226	206	186	157
80	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	315	275	255	235	216	196	177	147
100	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	305	265	245	226	206	186	167	137

P355NH EN10222-4 (Forging, Carbon Steel, April 2002)

1.0565 Specific gravity : 7.85 Elongation : 21 % Poisson Factor : 0.3 Reference Temp. : 0 °C

Modulus of elasticity

°C	*-100*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*
MPa×10^3	207	201	196	193	189	187	184	178	170	160

Coefficients of thermal expansion

°C	*-100*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*	*500*	*550*
mm/mm×10^{-6}	9.9	10.9	11.5	11.9	12.3	12.6	12.9	13.3	13.6	13.9	14.2	14.4

Tensile strength — Limits apply on thickness (mm).

100	*°C*	*20*
	MPa	470
150	*°C*	*20*
	MPa	470
250	*°C*	*20*
	MPa	470
375	*°C*	*20*
	MPa	470
400	*°C*	*20*
	MPa	470

Yield strength 0.2% — Limits apply on thickness (mm).

100	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	305	294	275	255	235	216	196	167
150	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	285	275	255	235	216	196	177	147
250	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	285	255	235	216	196	177	157	127
375	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	265	255	235	216	196	177	157	127
400	*°C*	*20*	*100*	*150*	*200*	*250*	*300*	*350*	*400*
	MPa	265	235	215	197	179	160	142	117

Codes, Guidelines and Standards Implemented.

Pressure vessel design code :
- AD-MERKBLAETTER 2000 (11-2007)
- B 0, Edition 05.2007
- B 1, Edition 10.2000
- B 2, Edition 10.2000
- B 3, Edition 10.2000
- B 5, Edition 08.2007
- B 6, Edition 10.2006
- B 7, Edition 08.2007
- B 8, Edition 05.2007
- B 9, Edition 11.2007

Design code of tubesheets :
- EN 13445:2002 V26 (2007-04)

Manufacturing standard :
- TEMA 9th Edition – June 2007

Additional requirements :
- PED 97/23/EC
- Lurgi Standards and Regulations
- DIN Standards
- DIN EN Standards

Local load design method:
- WRC 107 (2002-10)

Standard of flange ratings :
- ASME B16.5-2003

Standard of pipes:
- NF A 49

Standard of material :

EN10269 November 1999	25CrMo4	Bolting
EN10028-3 May 2003	P355NL1	Plate
EN10216-3 December 2002	P355NL1	Seamless pipe
EN10222-4 April 2002	P355NH	Forging

Units :
- SI

Design Conditions.

	Tube (comp. 2)	Shell (comp. 1)	/
Design pressure, internal :	0.58 MPa	1 MPa	/
Design temp., internal :	167 °C	400 °C	/
Height of operating liquid :	0 mm	0 mm	/
Operating fluid spec. gravity :	1	1	/
Corrosion allowance :	3 mm	3 mm	/
Design pressure, external :	-0.103 MPa	-0.103 MPa	/
Design temp., external :	167 °C	177 °C	/
Test pressure :	0.859 MPa	2.135 MPa	/
Test fluid spec. gravity:	1	1	/
Insulation thickness :	70 mm	100 mm	/
Weight/density of insulation :	35 kg/m³	35 kg/m³	/
Category :			/
Nominal stress :	1	1	/

Allowable stresses and safety factors

AD B0 / AD B6

f	allowable stress.
R_m	tensile strength
$R_{p0.2}$	yield strength 0,2 %
R_{p1}	yield strength 1 %
σ_R	Average stress to cause rupture at the end of 100000 hours.

Flanges

In operation	$f = f \times 1$
In test and gasket seating	$f = f \times 1$

Tube (comp. 2)	Allowable stress f					
Materials	Normal conditions		Exceptional and test conditions		Creep	
Excluding bolting	B0	B6	B0	B6	B0	B6
Carbon steel	$R_{p0.2}$ / 1.5	$R_{p0.2}$ / 1.6	$R_{p0.2}$ / 1.05	$R_{p0.2}$ / 1.1	σ_R / 1.5	σ_R / 1.6
Stainless steel	R_{p1} / 1.5	R_{p1} / 1.6	R_{p1} / 1.05	R_{p1} / 1.1	σ_R / 1.5	σ_R / 1.6
Copper alloy	R_m / 3.5	R_m / 4	R_m / 2.5	R_m / 2.5	σ_R / 3.5	σ_R / 4
Aluminum alloy	R_{p1} / 1.5	R_{p1} / 1.6	R_{p1} / 1.05	R_{p1} / 1.1	σ_R / 1.5	σ_R / 1.6
Nickel alloy	$R_{p0.2}$ / 1.5	$R_{p0.2}$ / 1.6	$R_{p0.2}$ / 1.05	$R_{p0.2}$ / 1.1	σ_R / 1.5	σ_R / 1.6
Titanium/Zirconium	$R_{p0.2}$ / 1.5	$R_{p0.2}$ / 1.6	$R_{p0.2}$ / 1.05	$R_{p0.2}$ / 1.1	σ_R / 1.5	σ_R / 1.6
Cast steel	$R_{p0.2}$ / 2	$R_{p0.2}$ / 2	$R_{p0.2}$ / 1.4	$R_{p0.2}$ / 1.5	σ_R / 2	σ_R / 2
Bolting	Standard	Neckdown	Standard	Neckdown	Standard	Neckdown
Carbon steel	$R_{p0.2}$ / 1.8	$R_{p0.2}$ / 1.5	$R_{p0.2}$ / 1.3	$R_{p0.2}$ / 1.1	σ_R / 1.8	σ_R / 1.5
Stainless steel	R_{p1} / 1.8	R_{p1} / 1.5	R_{p1} / 1.3	R_{p1} / 1.1	σ_R / 1.8	σ_R / 1.5

Shell (comp. 1)	Allowable stress f					
Materials	Normal conditions		Exceptional and test conditions		Creep	
Excluding bolting	B0	B6	B0	B6	B0	B6
Carbon steel	$R_{p0.2}$ / 1.5	$R_{p0.2}$ / 1.6	$R_{p0.2}$ / 1.05	$R_{p0.2}$ / 1.1	σ_R / 1.5	σ_R / 1.6
Stainless steel	R_{p1} / 1.5	R_{p1} / 1.6	R_{p1} / 1.05	R_{p1} / 1.1	σ_R / 1.5	σ_R / 1.6
Copper alloy	R_m / 3.5	R_m / 4	R_m / 2.5	R_m / 2.5	σ_R / 3.5	σ_R / 4
Aluminum alloy	R_{p1} / 1.5	R_{p1} / 1.6	R_{p1} / 1.05	R_{p1} / 1.1	σ_R / 1.5	σ_R / 1.6
Nickel alloy	$R_{p0.2}$ / 1.5	$R_{p0.2}$ / 1.6	$R_{p0.2}$ / 1.05	$R_{p0.2}$ / 1.1	σ_R / 1.5	σ_R / 1.6
Titanium/Zirconium	$R_{p0.2}$ / 1.5	$R_{p0.2}$ / 1.6	$R_{p0.2}$ / 1.05	$R_{p0.2}$ / 1.1	σ_R / 1.5	σ_R / 1.6
Cast steel	$R_{p0.2}$ / 2	$R_{p0.2}$ / 2	$R_{p0.2}$ / 1.4	$R_{p0.2}$ / 1.5	σ_R / 2	σ_R / 2
Bolting	Standard	Neckdown	Standard	Neckdown	Standard	Neckdown
Carbon steel	$R_{p0.2}$ / 1.8	$R_{p0.2}$ / 1.5	$R_{p0.2}$ / 1.3	$R_{p0.2}$ / 1.1	σ_R / 1.8	σ_R / 1.5
Stainless steel	R_{p1} / 1.8	R_{p1} / 1.5	R_{p1} / 1.3	R_{p1} / 1.1	σ_R / 1.8	σ_R / 1.5

Test Pressure

AD HP 30

$p_p = Fp \cdot p$	$F_p = \max [1,43 ; 1,25 (K_{20} / K_\theta)]$

p = design pressure
K_{20} = design strength value at test temperature
K_θ = design strength value at design temperature

For each component	p (MPa)	Test factor fixed	K_{20} (MPa)	K_θ (MPa)	s_e (mm)	c (mm)	p_p (MPa)
Korbbogen Type Head (01) TS01	0.58	/	335	282.84	20	3	0.859
Shell (02) TS02	0.58	/	345	290.84	16	3	0.86
Shell (06) SS01	1	/	345	202.01	16	3	2.135
Shell (07) SS01	1	/	345	202.01	16	3	2.135
Shell (11) TS03	0.58	/	345	290.84	16	3	0.86
Korbbogen Type Head (12) TS04	0.58	/	345	290.84	16	3	0.86

	Tube (comp. 2)	Shell (comp. 1)	/
Test pressure at the top P_e :	0.859 MPa	2.135 MPa	/

PED : P_t = MAX [1,43 P_s ; 1,25 P_s (f_a / f_t)]

P_s = design pressure
f_a = allowable stress at room temperature, normal condition
f_t = allowable stress at design temperature, normal condition

For each component	P_s (MPa)	Test factor fixed	f_a (MPa)	f_t (MPa)	e (mm)	c (mm)	P_t (MPa)
Korbbogen Type Head (01) TS01	0.58	/	335	282.84	20	3	0.859
Shell (02) TS02	0.58	/	345	290.84	16	3	0.86
Shell (06) SS01	1	/	345	202.01	16	3	2.135
Shell (07) SS01	1	/	345	202.01	16	3	2.135
Shell (11) TS03	0.58	/	345	290.84	16	3	0.86
Korbbogen Type Head (12) TS04	0.58	/	345	290.84	16	3	0.86

	Tube (comp. 2)	Shell (comp. 1)	/
Test pressure at the top P_e :	0.86 MPa	2.135 MPa	/

AD HP 30 4.10 : Vertical vessel : $p'_p = p_p + \Delta p_p$

AD HP 30 4.10.1 : Test in vertical position, pressure measured at the top of the vessel in vertical position
$\Delta p_p = 0.1 (\gamma_F H_F - \gamma_P H) \geq 0$

AD HP 30 4.10.2 : Test in horizontal position before a test in vertical position, pressure measured at the top of the vessel in horizontal position : $\Delta p_p = 0$

AD HP 30 4.10.3 : Test in horizontal position alone, pressure measured at the top of the vessel in horizontal position
$\Delta p_p = \max [0.1 \gamma_P H ; 0.1 \gamma_F H_F]$

H_F = liquid level in operation
H = liquid level in test
γ_F = Relative density of the liquid in operation
γ_P = Relative density of the liquid in test

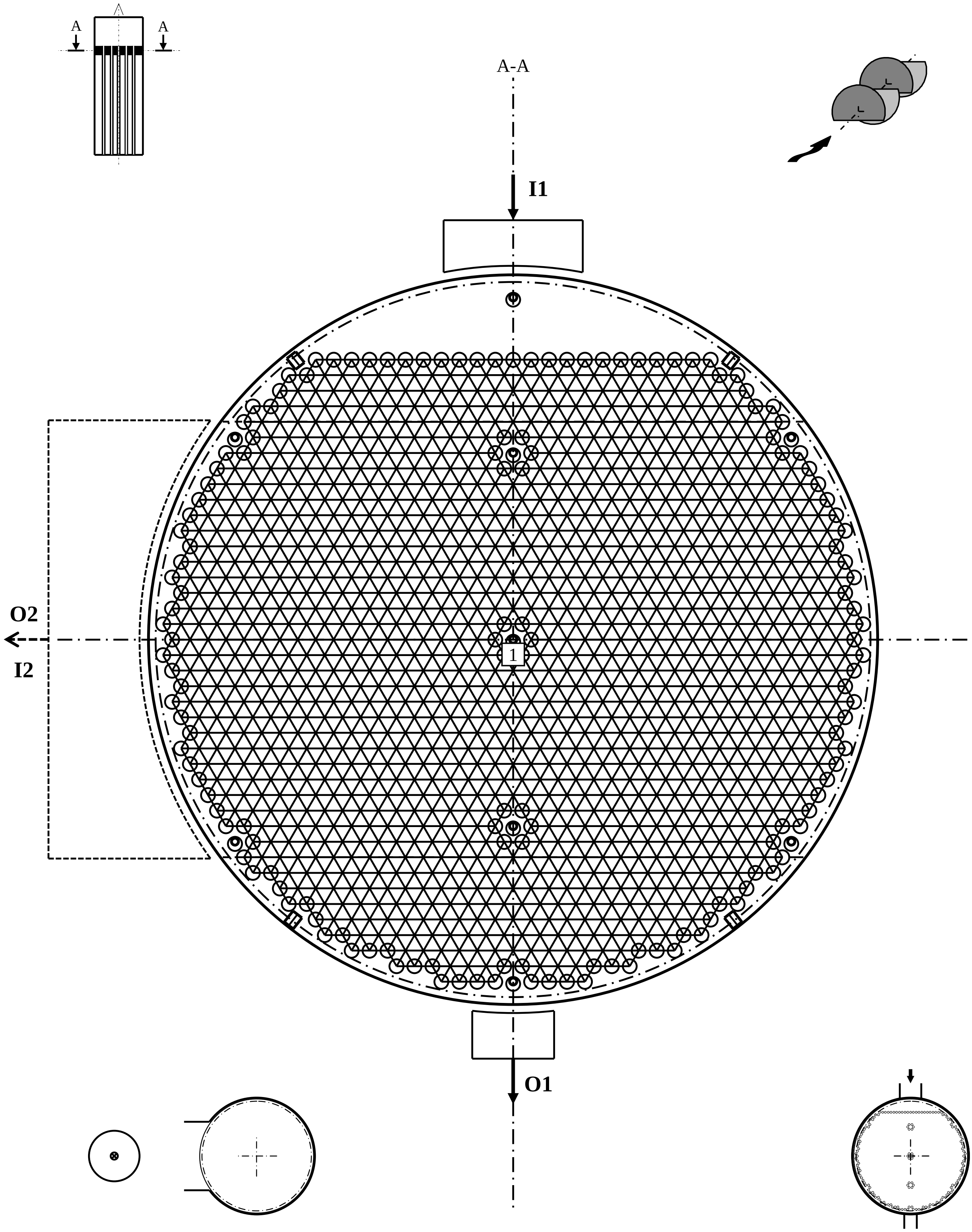
	Tube (comp. 2)	Shell (comp. 1)	/
Design pressure p :	0.58 MPa	1 MPa	/
Test pressure at the top p_p :	0.859 MPa	2.135 MPa	/
Δp_p AD HP 30 4.10.1	/	/	/
Δp_p AD HP 30 4.10.3	/	/	/

Hydrostatic Pressure

AD HP 30

Type of components	Operation				Test						
						Horizontal			Vertical		
	specific gravity	liquid level	hydrostatic height	hydrostatic pressure	specific gravity	liquid level	hydrostatic height	hydrostatic pressure	liquid level	hydrostatic height	hydrostatic pressure
		(mm)	(mm)	(MPa)		(mm)	(mm)	(MPa)	(mm)	(mm)	(MPa)
Shell(s)											
01 TS01	1	0.00	0.00	0.0000	1	1,300.00	1,300.00	0.0127	328.69	7,163.69	0.0000
02 TS02	1	0.00	0.00	0.0000	1	1,300.00	1,300.00	0.0127	320.00	6,835.00	0.0000
03 GF01	1	0.00	0.00	0.0000	1	1,300.00	1,300.00	0.0127	0.00	6,515.00	0.0000
04 space	/	/	/	/	/	/	/	/	/	/	/
05 TT01	1	0.00	0.00	0.0000	1	0.00	0.00	0.0000	0.00	4,851.00	0.0000
06 SS01	1	0.00	0.00	0.0000	1	1,300.00	1,300.00	0.0127	3,091.00	4,851.00	0.0000
07 SS01	1	0.00	0.00	0.0000	1	1,300.00	1,300.00	0.0127	1,760.00	1,760.00	0.0000
08 TT02	1	0.00	0.00	0.0000	1	0.00	0.00	0.0000	0.00	1,979.05	0.0000
09 space	/	/	/	/	/	/	/	/	/	/	/
10 GF02	1	0.00	0.00	0.0000	1	1,300.00	1,300.00	0.0127	0.00	1,972.05	0.0000
11 TS03	1	0.00	0.00	0.0000	1	1,300.00	1,300.00	0.0127	1,650.00	1,972.05	0.0000
12 TS04	1	0.00	0.00	0.0000	1	1,300.00	1,300.00	0.0127	322.05	322.05	0.0000
Opening(s)											
1 I1	1	/	0.00	0.0000	1	/	1,300.00	0.0127	/	524.00	0.0000
2 O1	1	/	0.00	0.0000	1	/	1,300.00	0.0127	/	4,494.00	0.0000
3 O2	1	/	0.00	0.0000	1	/	1,300.00	0.0127	/	1,123.05	0.0000
4 I2	1	/	0.00	0.0000	1	/	1,300.00	0.0127	/	7,163.69	0.0000
5 V1	1	/	0.00	0.0000	1	/	1,300.00	0.0127	/	0.00	0.0000
6 T	1	/	0.00	0.0000	1	/	1,300.00	0.0127	/	1,123.05	0.0000

Tube layout.



Tube layout report.

Shell inside diameter :	1,300 mm	Outer tube limit diameter	1,274.23 mm
Baffle outside diameter :	1,294 mm	Tube pitch :	32 mm
Tube outside diameter :	25 mm	Number of tubes :	1321
Mean deviation :	- %	Number of tie rods :	9
Variance factor :	- %	Number of sealing strips :	2
Mean tolerance :	- %	Number of bypass tubes :	0
Max. pass tolerance :	- %	Number of sliding rails :	2
Actual shell inlet free height :	13.5 mm	Actual shell outlet free height :	13.5 mm

Pass number	Number of tubes	Adj. Tol.	Adj. Tol.
1	1321	Tol 1 : 0.00 %	

No. of support plates = 0	type	No.	area cut
No. of baffles (Segmental) = 8	Bottom	4	191,013.1 mm²
	Top	4	191,013.1 mm²

Unsupported tube spans (calculated values) :
between two tubesheets (both ends fixed) = 4,717 mm between a tubesheet and a tube support (one end fixed, the other pinned) = 1,164 mm between two tube supports (both ends pinned) = 1,000 mm

Unsupported tube spans (fixed value) :
between a tubesheet and a tube support (one end fixed, the other pinned) = /

Flow section determination.

Minimum inside depth of channels.

The minimum cross-over area for flow between successive tube passes is at least equal to 1.3 times the flow area through the tubes of one pass.
Channel inlet : 50 ≤ 1,657 mm
Channel outlet (or rear box) : 50 ≤ 327 mm (for a floating head , it's the length of flange under the crown)

TEMA RGP-RCB-4.62 Shell or Bundle Entrance and Exit Areas.

Outer tube limit diameter : OTL = 1,274.23 mm	Tube pitch : P_t = 32 mm
Factor indicating tube pitch type and orientation : F_2 = 1	Tube outside diameter : D_t = 25 mm
Impingement plate length : L_p = 0 mm	Impingement plate edge length : I_p = 0 mm

Fluid velocity		Inlet	Outlet
Nozzle :	ρV^2_n =	0 J/m³	0 J/m³
Shell :	ρV^2_s =	0 J/m³	0 J/m³
Bundle :	ρV^2_b =	0 J/m³	0 J/m³

Shell inside diameter :	D_s =	1,300 mm	1,300 mm
Nozzle diameter :	D_n =	248 mm	146.3 mm

RGP-RCB-4.621 et 4.622 Shell entrance or exit area		Inlet	Outlet
Factor indicating presence of impingement plate :	F_1 =	1	1
Free height at nozzle centerline :	h_1 =	138.67 mm	27.82 mm
Free height at nozzle edge :	$h_2 = h_1 - 0.5[D_s - (D_s^2 - D_n^2)^{0.5}]$ =	126.73 mm	23.69 mm
Average free height above tube bundle or impingement plate :	$h = 0.5(h_1 + h_2)$ =	132.7 mm	25.75 mm
Minimal area required :	$A_{s,min} = \frac{\pi D_n^2}{4} \frac{\rho V_s^2}{\rho V_n^2}$ =	48,305.1 mm²	16,810.4 mm²
Approximate shell area :	$A_s = \pi D_n h + F_1 \left(\frac{\pi D_n^2}{4}\right) \frac{(P_t - D_t)}{F_2 P_t}$ =	113,955.9 mm²	15,514 mm²
Required free height at nozzle centerline :	$h_{1,min}$ =	54.41 mm	30.64 mm

RGP-RCB-4.623 4.624 Bundle entrance or exit area		Inlet	Outlet
Effective chord distance across bundle :	K =	760.15 mm	274.27 mm
Area of imingement plate :	A_p =	0 mm²	0 mm²
Unrestricted longitudinal flow area :	A_l =	0 mm²	0 mm²
Baffle spacing :	B_s =	664 mm	553 mm
Minimal area required :	$A_{b,min} = \frac{\pi D_n^2}{4} \frac{\rho V_b^2}{\rho V_n^2}$ =	48,305.1 mm²	16,810.4 mm²
Approximate bundle area :	$A_b = B_s(D_s - OTL) + (B_s K - A_p)\frac{P_t - D_t}{F_2 P_t} + A_l$ =	127,522.8 mm²	47,428.2 mm²
Required baffle spacing :	$B_{s,min}$ =	251.52 mm	196 mm

Element(s) of geometry in internal pressure

Korbbogen head TS01 internal pressure Channel head

```
DESIGN CODE    AD MERK. / B3 and B9 MATERIAL: P355NL1

DESIGN PRESSURE P              0.5800 MPa
TEMPERATURE                    167.0  °C
C: CORROSION  3.00 mm +ALLOWANCES  0.00 mm       X-RAY.         : 100%
ALLOWABLE ST. AT DESIGN TEMP KS 188.56 MPa
ALLOW. STRESS in TESTING KSE    319.05 MPa
YOUNG'S MODULUS AT DES. TEMP. E        191640.00 MPa
YOUNG'S MODULUS AT ROOM TEMP. E20      201000.00 MPa
JOINT EFFICIENCY V               1.00          HEAT TREATMENT :   NO
OUTSIDE DIAMETER   DA         1340.00 mm
INSIDE SPHERICAL RADIUS R     1072.00 mm
EXTERNAL HEAD DEPTH H          348.69 mm
CYLINDRICAL HEIGHT MIN H1       60.00 mm
KNUCKLE RADIUS RC              206.36 mm


       1-THICKNESS REQUIRED TO WITHSTAND TO DESIGN PRESSURE

            * NO OPENING TAKEN INTO ACCOUNT (PDI=0)

                 PDI/DA....................................=     0.000 mm
                 (EP-C)/DA= 0.0127-> AD B3 fig 4/8 ->BETA   =     1.834
                 MIN. THICKNESS PRESCRIBED/CALCULATED ......=     20.00 mm
                 CONNECTED SHELL THICKNESS..................=     16.00 mm
                 KNUCKLE THICKNESS = DA*P*BETA/4/KS/V+C.....=      4.89 mm
                 HEAD  THICKNESS = 2*(R+EP)*P/(4*KS*V+P)+C..=      4.68 mm
                 CYL. PART THICKNESS = DA*P/(2*KS*V+P)+C....=      5.06 mm
                 EP = THICKNESS ADOPTED.....................=     20.00 mm

       2-HORIZONTAL TEST STRESS in CORRODED CONDITION

                 *TEST PRESSURE PE..........................=    0.8717 MPa
                 STRESS [8.1.1] = 2*PE(R+EP)/(4V(EP-C))
                 STRESS [8.1.3] = PE*DA*BETA/(4V(EP-C))
                 STRESS (cylindrical part) = PE(DA-EP+C)/(2V(EP-C)
                                              MAX. STRESS =     33.92 MPa

       3- CAUTION, WELDED JOINT GUIDELINES VALID

                 DISTANCE KNUKLE TO WELDING
                 X = MAX(100,3.0*EP)........................=    100.00 mm
```

Korbbogen head TS04 internal pressure Channel head

```
DESIGN CODE    AD MERK. / B3 and B9 MATERIAL: P355NL1

DESIGN PRESSURE P              0.5800 MPa
TEMPERATURE                    167.0  °C
C: CORROSION  3.00 mm +ALLOWANCES  0.00 mm       X-RAY.         : 100%
ALLOWABLE ST. AT DESIGN TEMP KS 193.89 MPa
ALLOW. STRESS in TESTING KSE    328.57 MPa
YOUNG'S MODULUS AT DES. TEMP. E        191640.00 MPa
YOUNG'S MODULUS AT ROOM TEMP. E20      201000.00 MPa
JOINT EFFICIENCY V               1.00           HEAT TREATMENT :   NO
OUTSIDE DIAMETER   DA         1332.00 mm
INSIDE SPHERICAL RADIUS R     1065.60 mm
EXTERNAL HEAD DEPTH H          345.05 mm
CYLINDRICAL HEIGHT MIN H1       48.00 mm
KNUCKLE RADIUS RC              205.13 mm


       1-THICKNESS REQUIRED TO WITHSTAND TO DESIGN PRESSURE

            * NO OPENING TAKEN INTO ACCOUNT (PDI=0)

                 PDI/DA....................................=     0.000 mm
                 (EP-C)/DA= 0.0098-> AD B3 fig 4/8 ->BETA   =     1.910
                 MIN. THICKNESS PRESCRIBED/CALCULATED ......=     16.00 mm
                 CONNECTED SHELL THICKNESS..................=     16.00 mm
                 KNUCKLE THICKNESS = DA*P*BETA/4/KS/V+C.....=      4.90 mm
                 HEAD  THICKNESS = 2*(R+EP)*P/(4*KS*V+P)+C..=      4.62 mm
                 CYL. PART THICKNESS = DA*P/(2*KS*V+P)+C....=      4.99 mm
                 EP = THICKNESS ADOPTED.....................=     16.00 mm

       2-HORIZONTAL TEST STRESS in CORRODED CONDITION

                 *TEST PRESSURE PE..........................=    0.8717 MPa
                 STRESS [8.1.1] = 2*PE(R+EP)/(4V(EP-C))
                 STRESS [8.1.3] = PE*DA*BETA/(4V(EP-C))
                 STRESS (cylindrical part) = PE(DA-EP+C)/(2V(EP-C)
                                                MAX. STRESS =     44.22 MPa

       3- CAUTION, WELDED JOINT GUIDELINES VALID

                 DISTANCE KNUKLE TO WELDING
                 X = MAX(100,3.0*EP)........................=    100.00 mm
```

Cylindrical shell under internal pressure.

AD-Merkblatt B1 and B 10

p = internal pressure	K/S = maximum allowable stress	T = temperature in operation	
D_a = outside diameter	D_i = inside diameter	v = joint efficiency	
s_e = actual wall thickness	c = corrosion allowance + tolerance	tol = tolerance for pipes	
σ = circular stress	σ_{va} = stress on the outer surface	σ_{vi} = stress on the inner surface	
s = required wall thickness including allowances		s_e shall be $\geq s$	$s = (e + c) / tol$
e = minimum required thickness to withstand to pressure		K/S shall be $\geq \sigma$	$e_u = (s_e \times tol) - c$

if $D_a/D_i \leq 1{,}2$ or if pipe (with $D_a \leq$ 200mm) and $D_a/D_i \leq 1{,}7$	$e = D_a.p / (2K/S.v + p)$	$\sigma = (D_a.p / e_u - p) / (2\,v)$		
if $D_a/D_i \leq 1{,}5$	$e = D_a.p / (2{,}3K/S - p)$	$\sigma_{vi} = p\,(D_a + e_u) / (2{,}3\,e_u)$	$\sigma_{va} = p\,(D_a - 3.e_u) / (2{,}3\,e_u)$	$\sigma = \max(\sigma_{vi}, \sigma_{va})$

Shell (02) : TS02 (Channel barrel)

P355NL1	Plate			Carbon Steel				Schedule : /	DN : /	
s_e = 16.000 mm	D_i = 1,300.00 mm D_e = 1,332.00 mm	$Tol_{\%}$ = / Cor. = 3 mm		Tol. = 0 mm			PWHT : no TEMA RCB-3.13 = 12.7 mm		x-ray : Full	
	p (MPa)	p_h (MPa)	T (°C)	K/S (MPa)	v	e_u (mm)	σ (MPa)	p_a (MPa)	e (mm)	s (mm)
Operation *N*	0.58	0	167	193.89	1	13.000	29.42	3.82	1.989	4.989
Horizontal test *X*	0.8717	0.0127	20	328.57	1	13.000	44.22	6.48	1.765	4.765
PMA (at 167 °C, corroded) = 3.82 MPa				PMA (at 20 °C, new) = 5.59 MPa						

Shell (06,07) : SS01 (Shell barrel)

P355NL1	Plate			Carbon Steel				Schedule : /	DN : /	
s_e = 16.000 mm	D_i = 1,300.00 mm D_e = 1,332.00 mm	$Tol_{\%}$ = / Cor. = 3 mm		Tol. = 0 mm			PWHT : no TEMA RCB-3.13 = 12.7 mm		x-ray : Full	
	p (MPa)	p_h (MPa)	T (°C)	K/S (MPa)	v	e_u (mm)	σ (MPa)	p_a (MPa)	e (mm)	s (mm)
Operation *N*	1	0	400	134.67	1	13.000	50.73	2.65	4.927	7.927
Horizontal test *X*	2.1477	0.0127	20	328.57	1	13.000	108.96	6.48	4.339	7.339
PMA (at 400 °C, corroded) = 2.65 MPa				PMA (at 20 °C, new) = 5.59 MPa						

Shell (11) : TS03 (Channel barrel)

P355NL1	Plate			Carbon Steel				Schedule : /	DN : /	
s_e = 16.000 mm	D_i = 1,300.00 mm D_e = 1,332.00 mm	$Tol_{\%}$ = / Cor. = 3 mm		Tol. = 0 mm			PWHT : no TEMA RCB-3.13 = 12.7 mm		x-ray : Full	
	p (MPa)	p_h (MPa)	T (°C)	K/S (MPa)	v	e_u (mm)	σ (MPa)	p_a (MPa)	e (mm)	s (mm)
Operation *N*	0.58	0	167	193.89	1	13.000	29.42	3.82	1.989	4.989
Horizontal test *X*	0.8717	0.0127	20	328.57	1	13.000	44.22	6.48	1.765	4.765
PMA (at 167 °C, corroded) = 3.82 MPa				PMA (at 20 °C, new) = 5.59 MPa						

Element(s) of geometry in external pressure
External Pressure - Korbbogen head (element No. 1) Channel head

```
Mark:  1 TS01

Code     AD MERK. / B3 and B9

  DESIGN CONDITIONS (OPERATION)
    External pressure                        p =    1.030 bar (  0.10 MPA)
    Design temperature                                        167.0   °C

  GEOMETRY
    Outside diameter                               Da =     1340.000 mm
    Inside radius of the crown portion +c1+c2       R =     1075.000 mm
    Thickness new                                  se =       20.000 mm
    Corrosion                                      c1 =        3.000 mm
    Tolerance                                      c2 =        0.000 mm
    Checked thickness                        se-c1-c2 =       17.000 mm
    Material P355NL1
    Allowable stress                              K/S =      188.56  MPa
    Modulus of elasticity                           E =   191640.000 MPa
    Joint efficiency                                v =        1.00

------------------------------------------------------------------------------

  ADM B3 Domed ends subject to internal or external pressure

   1 Scope
    b) Semi-ellipsoidal ends
    (se - c1 - c2)/Da                                 =        0.01269

                Relation (4) 0.001 <= (se - c1 - c2)/Da <= 0.1  checked

   8 Calculation
    8.2 External pressure
    8.2.1 Limiting of permanent elongation
    Safety factor increased by 20%, according to § 4.3
    Resulting allowable stress                    K/S =      157.133 MPa

    Use of §8.1.3 with the increased coefficient S
    Head minimum thickness
    s = Da.p.beta / (40.K/S.v) + c1 + c2            s =        3.403 mm
    beta (Fig(8))                                beta =        1.834
                                   Opening diameter di =       0.000 mm
                                                 di/Da =       0.0000
                                         se-c1-c2 / Da =       0.0127

                Relation s <= se checked

    8.2.2 Elastic buckling
    Allowable pressure
    pmax = 3.66 E/Sk ((se-c1-c2)/R)**2  =    56.104 bar (      5.61 MPA)
                       Sk = 3 + 0.002/((se-c1-c2)/R) =        3.126

              pmax >= p ,the design thickness se is sufficient

    8.2.3 Plastic buckling
    Safety factor increased by 20%, and > 2.4 according to § 4.4
    Resulting allowable stress                    K/S =      117.850 MPa
    s = Da.p / (40.K/S.v+p) + c1 + c2               s =        3.477 mm
    Da = 2(R+se)                                   Da =     2184.000 mm
                                                    v = 1

                Relation s <= se checked
```

External Pressure - Shell (element No. 2) Channel barrel

```
Mark:  2 TS02

Code     AD MERK. – B6

  DESIGN CONDITIONS (OPERATION)

    External pressure                       p =    1.030 bar (  0.10 MPA)
    Design temperature                                       167.0   °C

  GEOMETRY
    Ends of section :

      * Bottom :
        Head (component No. 1)
        Support Line level :                                   0.000 mm

      * Top :
        Flange (element No.  3)
        Support Line level :                                 320.000 mm

    Calculation length:                             L =      320.000 mm

    Elements considered :
   Indice  Diameter       se-c1-c2       Young's modulus    Temperature
     2   1300.000 mm    13.000 mm        191640.00 MPa      167.00 °C

    Element diameter                               Da =     1332.000 mm
    Checked thickness                        se-c1-c2 =       13.000 mm

    Allowable stress                              K/S =      181.77  MPa
    Modulus of elasticity                           E =   191640.000 MPa
    Poisson's ratio                                nu =        0.3

------------------------------------------------------------------------------

  ADM B6 - Cylindrical shells subjected to external pressure

    7.2 Design calculations for elastic buckling
    7.2.1
    p1 (Equation(1))                               p1 =       86.629 bar
                            Z = 0.5 (pi.Da/L) =                6.538
         n = int(1.63 (Da**3/(L**2.(se-c1-c2))**0.25) =       11

    7.3 Design calculations for plastic deformation
    Da/L                                              =        4.1625
    7.3.1 Da/L <= 5
    p2 (Equation (4))                              p2 =       25.597 bar
    Out-of-roundness                                u =        1.500 %

    Allowable pressure
    pmax = min(p1, p2)                   =     25.597 bar (      2.56 MPA)

              pmax >= p ,the design thickness se is sufficient
```

External Pressure - Shell (element No. 3) Shell barrel

```
Mark:  6 SS01   Shell barrel
Mark:  7 SS01   Shell barrel

Code     AD MERK. B6

  DESIGN CONDITIONS (OPERATION)

    External pressure                        p =    1.030 bar (  0.10 MPA)
    Design temperature                                    177.0   °C

  GEOMETRY
    Ends of section :

      * Bottom :
        Tubesheet (element No. 5)
        Support Line level :                              418.000 mm

      * Top :
        Tubesheet (element No. 8)
        Support Line level :                             5087.000 mm

    Calculation length:                              L =     4669.000 mm

    Elements considered :
   Indice  Diameter       se-c1-c2       Young's modulus    Temperature
      6   1300.000 mm    13.000 mm        190840.00 MPa      177.00 °C
      7   1300.000 mm    13.000 mm        190840.00 MPa      177.00 °C

    Element diameter                                Da =     1332.000 mm
    Checked thickness                         se-c1-c2 =       13.000 mm

    Allowable stress                               K/S =      178.78  MPa
    Modulus of elasticity                            E =   190840.000 MPa
    Poisson's ratio                                 nu =        0.3


------------------------------------------------------------------------------

  ADM B6 - Cylindrical shells subjected to external pressure

    7.2 Design calculations for elastic buckling
    7.2.1
    p1 (Equation(1))                                p1 =        4.363 bar
                               Z = 0.5 (pi.Da/L) =              0.448
         n = int(1.63 (Da**3/(L**2.(se-c1-c2))**0.25) =        3

    7.3 Design calculations for plastic deformation
    Da/L                                               =        0.2853
    7.3.1 Da/L <= 5
    p2 (Equation (4))                               p2 =       10.995 bar
    Out-of-roundness                                 u =        1.500 %

    Allowable pressure
    pmax = min(p1, p2)                  =      4.363 bar (      0.44 MPA)

              pmax >= p ,the design thickness se is sufficient
```

External Pressure - Shell (element No. 4) Channel barrel

```
Mark: 11 TS03

Code     AD MERK. B6

  DESIGN CONDITIONS (OPERATION)

    External pressure                        p =    1.030 bar (  0.10 MPA)
    Design temperature                                      167.0   °C

  GEOMETRY
    Ends of section :

      * Bottom :
        Flange (element No. 10)
        Support Line level :                               5185.000 mm

      * Top :
        Head (component No.12)
        Support Line level :                               6835.000 mm

    Calculation length:                              L =     1650.000 mm

    Elements considered :
   Indice  Diameter       se-c1-c2       Young's modulus    Temperature
     11   1300.000 mm    13.000 mm        191640.00 MPa      167.00 °C

    Element diameter                                Da =     1332.000 mm
    Checked thickness                         se-c1-c2 =       13.000 mm

    Allowable stress                               K/S =      193.89  MPa
    Modulus of elasticity                            E =   191640.000 MPa
    Poisson's ratio                                 nu =        0.3

------------------------------------------------------------------------------

  ADM B6 - Cylindrical shells subjected to external pressure

    7.2 Design calculations for elastic buckling
    7.2.1
    p1 (Equation(1))                                p1 =       13.619 bar
                            Z = 0.5 (pi.Da/L) =               1.268
         n = int(1.63 (Da**3/(L**2.(se-c1-c2))**0.25) =        5

    7.3 Design calculations for plastic deformation
    Da/L                                               =        0.8073
    7.3.1 Da/L <= 5
    p2 (Equation (4))                               p2 =       37.847 bar
    Out-of-roundness                                 u =        0.000 %

    Allowable pressure
    pmax = min(p1, p2)                   =     13.619 bar (      1.36 MPA)

              pmax >= p ,the design thickness se is sufficient
```

External Pressure - Korbbogen head (element No. 5) Channel head

```
Mark: 12 TS04

Code     AD MERK. B3

  DESIGN CONDITIONS (OPERATION)
    External pressure                        p =    1.030 bar (  0.10 MPA)
    Design temperature                                   167.0   °C

  GEOMETRY
    Outside diameter                               Da =     1332.000 mm
    Inside radius of the crown portion +c1+c2       R =     1068.600 mm
    Thickness new                                  se =       16.000 mm
    Corrosion                                      c1 =        3.000 mm
    Tolerance                                      c2 =        0.000 mm
    Checked thickness                        se-c1-c2 =       13.000 mm
    Material P355NL1
    Allowable stress                              K/S =      193.89  MPa
    Modulus of elasticity                           E =   191640.000 MPa
    Joint efficiency                                v =        1.00

------------------------------------------------------------------------------

  ADM B3 Domed ends subject to internal or external pressure

   1 Scope
    b) Semi-ellipsoidal ends
    (se - c1 - c2)/Da                                 =        0.00976

                Relation (4) 0.001 <= (se - c1 - c2)/Da <= 0.1  checked

   8 Calculation
    8.2 External pressure
    8.2.1 Limiting of permanent elongation
    Safety factor increased by 20%, according to § 4.3
    Resulting allowable stress                    K/S =      161.577 MPa

    Use of §8.1.3 with the increased coefficient S
    Head minimum thickness
    s = Da.p.beta / (40.K/S.v) + c1 + c2            s =        3.405 mm
    beta (Fig(8))                                beta =        1.910
                                   Opening diameter di =       0.000 mm
                                                di/Da =        0.0000
                                       se-c1-c2 / Da =        0.0098

                Relation s <= se checked

    8.2.2 Elastic buckling
    Allowable pressure
    pmax = 3.66 E/Sk ((se-c1-c2)/R)**2  =    32.804 bar (      3.28 MPA)
                        Sk = 3 + 0.002/((se-c1-c2)/R) =        3.164

              pmax >= p ,the design thickness se is sufficient

    8.2.3 Plastic buckling
    Safety factor increased by 20%, and > 2.4 according to § 4.4
    Resulting allowable stress                    K/S =      121.183 MPa
    s = Da.p / (40.K/S.v+p) + c1 + c2               s =        3.460 mm
    Da = 2(R+se)                                   Da =     2163.200 mm
                                                    v = 1

                Relation s <= se checked
```

External Pressure - Summary (in operation)

Element	Component(s)		Diameter (mm)	Thickness (mm)
Element No. 1 Length : 0.00 mm ok (1)	1	KH	1,300.00	20.000
Element No. 2 Length : 320.00 mm ok (1)	2	SH	1,300.00	16.000
Element No. 3 Length : 4,669.00 mm ok (1)	6 7	SH SH	1,300.00 1,300.00	16.000 16.000
Element No. 4 Length : 1,650.00 mm ok (1)	11	SH	1,300.00	16.000
Element No. 5 Length : 0.00 mm ok (1)	12	KH	1,300.00	16.000

(1) : # = unchecked element (revise design)
0 = unchecked element, without external pessure (P=0)
ok = checked element

Body flange(s) and cover(s)

Shell flange calculation GF01 (In Operation)

```
 DESIGN CODE    :  AD MERK – B8 and B7      MATERIALS:  FLANGE    / BOLTING
        P355NH                     25CrMo4
 DESIGN PRESSURE P =  0.580 MPa
 TEMPERATURE  =   167.0 °C                 NON CORRODED DIMENSIONS :
 CORROSION C2  = 3.0    mm                  DI = 1300.0 mm   DA = 1502.0 mm
 TOLERANCE TOL = 1.6    mm                  DT = 1430.0 mm   DD = 1332.0 mm
 ALLOWABLE STRESS DES. TEMP./AMB.           S1 =   16.0 mm   SF =   24.0 mm
 FLANGE (KS/KSE) : 165.5 MPa /  271.4 MPa  HF =   72.0 mm   HFJ=   67.0 mm
 BOLTS  (KSB/KSBE): 168.9 MPa /  338.5 MPa HA =  109.0 mm   DL =   22.0 mm
                                            DEJ= 1351.0 mm
 WEIGHT  :    260. kg
 BOLTS   : N= 56  DB= 20.0 mm    DFI=  16.93 mm
 GASKET : WIDTH  19.0 mm THICKNESS  4.0 mm GROOVES NBER  0.00
 SETTING: BD= 19.0 mm  K0=  0.0000 mm  KD =   0.0 MPa K0*KD=  380.00 N/mm
 AT TEMP: BD= 19.0 mm  K1= 20.9000 mm  KDT=   0.0 MPa
 FULL-FACE GASKET : NO
 DESIGN COEFF.    :  SD= 1.20
 BOLTS WITH MACHINED CONTACT SURFACE : YES -> PHI= 1.00
 INTEGRAL FLANGE WITH TAPERED HUB

 FEMALE SINGLE FLANGE COUPLING OF  5.00 mm
CORRODED VALUES   :
 DI= 1306.0 mm    S1=   13.0 mm    SF=   21.0 mm
 HA=  102.4 mm    HF=   65.4 mm

 BOLT LOADS :
 FRB=P*PI*DI*DI/4........=  776970. N  FFB=P*PI*(DD*DD-DI*DI)/4=   31244. N
 FDB=P*PI*DD*SD*K1.......=   60871. N  FSB=FRB+FFB+FDB.........=  869085. N
 FDV=PI*DD*K0*KD.........= 1590149. N
 FDVP=0.2*FDV+0.8*SQRT(FDV*FSB)= 1258489. N
 FSBX=MAX(FSB)...........=  869085. N  FDVX=MAX(FDVP)..........= 1462548. N

 ACTUAL BOLT CROSS-SECTION :
 in SERVICE    : SBT = N*PI/4*DFI**2      =    12611. mm²
 in BOLTING-UP : SB  = N*PI/4*DFI**2      =    12611. mm²

 REQUIRED BOLT CROSS-SECTION :
 in SERVICE    : SBN' = FSB/KSB/PHI       =     5146. mm²
                 Dreq= SQRT(SBN'*4/N/PI)  =     10.82 mm
                 Dreq =< 20              -> C5 = 3.0 mm
                 SBN = N*PI*(Dreq+C5)**2/4=     8396. mm²
 in BOLTING-UP : SBA = FDV/KSBE/PHI       =     3718. mm²

 BSR =PI*DT/N=  80.2 mm     BSX = 5*DL= 110.0 mm    BSMIN=  53.0 mm
 Fso = FDVX =   1462548. N
 Load to apply on bolting Fso/N =     26117. N
REAL BOLT STRESSES:
 FSBX/SBT =       68.9 MPa
 Fso/SB   =      116.0 MPa
```

Shell flange calculation GF01 (In Operation)

```
 DESIGN CODE    :  AD MERK – B8 and B7      MATERIALS:  FLANGE    / BOLTING
        P355NH                       25CrMo4
 DESIGN PRESSURE P =  0.580 MPa
 TEMPERATURE  =   167.0 °C                 NON CORRODED DIMENSIONS :
 CORROSION C2  = 3.0    mm                 DI = 1300.0 mm   DA = 1502.0 mm
 TOLERANCE TOL = 1.6    mm                 DT = 1430.0 mm   DD = 1332.0 mm
 ALLOWABLE STRESS DES. TEMP./AMB.          S1 =   16.0 mm   SF =   24.0 mm
 FLANGE (KS/KSE) : 165.5 MPa /  271.4 MPa  HF =   72.0 mm   HFJ=   67.0 mm
 BOLTS  (KSB/KSBE): 168.9 MPa /  338.5 MPa HA =  109.0 mm   DL =   22.0 mm
                                           DEJ= 1351.0 mm
 WEIGHT  :    260. kg
 BOLTS   : N= 56  DB= 20.0 mm    DFI=  16.93 mm
 GASKET : WIDTH  19.0 mm THICKNESS  4.0 mm GROOVES NBER  0.00
 SETTING: BD= 19.0 mm  K0=  0.0000 mm  KD =   0.0 MPa K0*KD=  380.00 N/mm
 AT TEMP: BD= 19.0 mm  K1= 20.9000 mm  KDT=   0.0 MPa
 FULL-FACE GASKET : NO
 DESIGN COEFF.    :  SD= 1.20
 BOLTS WITH MACHINED CONTACT SURFACE : YES -> PHI= 1.00
 INTEGRAL FLANGE WITH TAPERED HUB

 FEMALE SINGLE FLANGE COUPLING OF  5.00 mm
CORRODED VALUES   :
 DI= 1306.0 mm    S1=   13.0 mm    SF=   21.0 mm
 HA=  102.4 mm    HF=   65.4 mm

DESIGN PARAMETERS :
 V= 0.50    DLP=V*DL=      11.00 mm   B  = DA-DI-2*DLP.....=     174.00 mm
 SFC= MIN(SF,HF/3)..=      21.00 mm   SM = (SF+S1)/2.......=      17.00 mm
 B1 = (HA-HF)/HF....=  0.57   B0=(1+2*B1*SM/B)/(1+2*SM*(B1*B1+2*B1)/B)=0.87
 Z=(DI+SFC)*SFC*SFC.=    585207. mm3  Z1=0.75*(DI+S1)*S1*S1=    167183. mm3
 A  = (DT-DI-SFC)/2 =      51.50 mm   AB = (DT-DI-S1)/2....=      55.50 mm
 AD = (DT-DD)/2.....=      49.00 mm   ADB= (DT-DD)/2.......=      49.00 mm

DESIGN FOR BOLTING-UP CONDITION :
SECTION A-A :
 WAA=Fso*AD/KSE ............................=    264028. mm3
 HFAA=SQRT(MAX(0,(1.27*WAA-Z)/B))...........=       0.00 mm
SECTION B-B :
 WBA=Fso*ADB/KSE ...........................=    264028. mm3
 HFBA=B0*SQRT(MAX(0,(1.27*WBA-Z1)/B))........=      26.89 mm
DIN 2505 9.2  Flange deflection in the bolt circle   deltaF=     0.344 mm
                                           ATAN(deltaF/AD) =     0.402 °
DESIGN FOR SERVICE CONDITION :
SECTION A-A :
 WA=FSBX*A*/KS .............................=    270494. mm3
 HFA=SQRT(MAX(0,(1.27*WA-Z)/B)).............=       0.00 mm
SECTION B-B :
 WB=FSBX*AB*/KS ............................=    291503. mm3
 HFB=B0*SQRT(MAX(0,(1.27*WB-Z1)/B))..........=      29.55 mm

DIN 2505 9.2  Flange deflection in the bolt circle   deltaF=     0.237 mm
                                           ATAN(deltaF/AD) =     0.277 °

 HFMINI= MAX(HFAA,HFBA,HFA,HFB)+TOL.........=       31.2 mm
```

Shell flange calculation GF01 (In Test)

```
 DESIGN CODE    :  AD MERK – B8 and B7      MATERIALS:  FLANGE    / BOLTING
         P355NH                     25CrMo4
 DESIGN PRESSURE P =  0.859 MPa
 TEMPERATURE  =    20.0 ⁰C                    NON CORRODED DIMENSIONS :
 CORROSION C2  = 3.0    mm                    DI = 1300.0 mm   DA = 1502.0 mm
 TOLERANCE TOL = 1.6    mm                    DT = 1430.0 mm   DD = 1332.0 mm
 ALLOWABLE STRESS DES. TEMP./AMB.             S1 =   16.0 mm   SF =   24.0 mm
 FLANGE (KS/KSE) : 271.4 MPa /  271.4 MPa  HF =   72.0 mm   HFJ=   67.0 mm
 BOLTS  (KSB/KSBE): 338.5 MPa /  338.5 MPa HA =  109.0 mm   DL =   22.0 mm
                                          DEJ= 1351.0 mm
 WEIGHT  :    260. kg
 BOLTS   : N= 56  DB= 20.0 mm    DFI=  16.93 mm
 GASKET : WIDTH  19.0 mm THICKNESS  4.0 mm GROOVES NBER  0.00
 SETTING: BD= 19.0 mm  K0=  0.0000 mm  KD =   0.0 MPa K0*KD=  380.00 N/mm
 AT TEMP: BD= 19.0 mm  K1= 20.9000 mm  KDT=   0.0 MPa
 FULL-FACE GASKET : NO
 DESIGN COEFF.    :  SD= 1.20
 BOLTS WITH MACHINED CONTACT SURFACE : YES -> PHI= 1.00
 INTEGRAL FLANGE WITH TAPERED HUB

 FEMALE SINGLE FLANGE COUPLING OF  5.00 mm
CORRODED VALUES   :
 DI= 1306.0 mm    S1=   13.0 mm    SF=   21.0 mm
 HA=  102.4 mm    HF=   65.4 mm

 BOLT LOADS :
 FRB=P*PI*DI*DI/4........= 1150719. N  FFB=P*PI*(DD*DD-DI*DI)/4=   46273. N
 FDB=P*PI*DD*SD*K1.......=   90152. N  FSP=FRB+FFB+FDB.........= 1287145. N
 FSPX=MAX(FSP)...........= 1287145. N
 ACTUAL BOLT CROSS-SECTION         :  SB  = N*PI/4*DFI**2 =     12611. mm2
 REQUIRED BOLT CROSS-SECTION       :  SBNE= FSP/KSB/PHI   =      3803. mm2
 BSR =PI*DT/N=  80.2 mm     BSX = 5*DL= 110.0 mm    BSMIN=  53.0 mm
REAL BOLT STRESSES:
 FSPX/SB  =      102.1 MPa
DESIGN PARAMETERS :
 V= 0.50    DLP=V*DL=      11.00 mm   B  = DA-DI-2*DLP.....=     174.00 mm
 SFC= MIN(SF,HF/3)..=      21.00 mm   SM = (SF+S1)/2.......=      17.00 mm
 B1 = (HA-HF)/HF....=  0.57   B0=(1+2*B1*SM/B)/(1+2*SM*(B1*B1+2*B1)/B)=0.87
 Z=(DI+SFC)*SFC*SFC.=    585207. mm3  Z1=0.75*(DI+S1)*S1*S1=    167183. mm3
 A  = (DT-DI-SFC)/2 =      51.50 mm   AB = (DT-DI-S1)/2....=      55.50 mm

DESIGN OF FLANGE THICKNESS :
SECTION A-A :
 WA=FSPX*A*/KSE.............................=    244218. mm3
 HFA=SQRT(MAX(0,(1.27*WA-Z)/B))..............=       0.00 mm
SECTION B-B :
 WB=FSPX*AB*/KSE............................=    263187. mm3
 HFB=B0*SQRT(MAX(0,(1.27*WB-Z1)/B))..........=      26.81 mm

DIN 2505 9.2  Flange deflection in the bolt circle   deltaF=     0.335 mm
                                          ATAN(deltaF/AD) =     0.391 ⁰

 HFMINI= MAX(HFA,HFB)+TOL...................=       28.4 mm
```

Shell flange calculation GF02 (In Operation)

```
 DESIGN CODE    :  AD MERK – B8 and B7      MATERIALS:  FLANGE    / BOLTING
        P355NH                        25CrMo4
 DESIGN PRESSURE P =  0.580 MPa
 TEMPERATURE  =   167.0 °C                NON CORRODED DIMENSIONS :
 CORROSION C2  = 3.0    mm                 DI = 1300.0 mm   DA = 1502.0 mm
 TOLERANCE TOL = 1.6    mm                 DT = 1430.0 mm   DD = 1332.0 mm
 ALLOWABLE STRESS DES. TEMP./AMB.          S1 =   16.0 mm   SF =   24.0 mm
 FLANGE (KS/KSE) : 165.5 MPa /  271.4 MPa  HF =   72.0 mm   HFJ=   67.0 mm
 BOLTS  (KSB/KSBE): 168.9 MPa /  338.5 MPa HA =  109.0 mm   DL =   22.0 mm
                                           DEJ= 1351.0 mm
 WEIGHT  :    260. kg
 BOLTS   : N= 56  DB= 20.0 mm    DFI=  16.93 mm
 GASKET : WIDTH  19.0 mm THICKNESS  4.0 mm GROOVES NBER  0.00
 SETTING: BD= 19.0 mm  K0=  0.0000 mm  KD =   0.0 MPa K0*KD=  380.00 N/mm
 AT TEMP: BD= 19.0 mm  K1= 20.9000 mm  KDT=   0.0 MPa
 FULL-FACE GASKET : NO
 DESIGN COEFF.    :  SD= 1.20
 BOLTS WITH MACHINED CONTACT SURFACE : YES -> PHI= 1.00
 INTEGRAL FLANGE WITH TAPERED HUB

 FEMALE SINGLE FLANGE COUPLING OF  5.00 mm
CORRODED VALUES   :
 DI= 1306.0 mm    S1=   13.0 mm    SF=   21.0 mm
 HA=  102.4 mm    HF=   65.4 mm

 BOLT LOADS :
 FRB=P*PI*DI*DI/4........=  776970. N  FFB=P*PI*(DD*DD-DI*DI)/4=   31244. N
 FDB=P*PI*DD*SD*K1.......=   60871. N  FSB=FRB+FFB+FDB.........=  869085. N
 FDV=PI*DD*K0*KD.........= 1590149. N
 FDVP=0.2*FDV+0.8*SQRT(FDV*FSB)= 1258489. N
 FSBX=MAX(FSB)...........=  869085. N  FDVX=MAX(FDVP)..........= 1462548. N

 ACTUAL BOLT CROSS-SECTION :
 in SERVICE    : SBT = N*PI/4*DFI**2      =    12611. mm2
 in BOLTING-UP : SB  = N*PI/4*DFI**2      =    12611. mm2

 REQUIRED BOLT CROSS-SECTION :
 in SERVICE    : SBN' = FSB/KSB/PHI       =     5146. mm2
                 Dreq= SQRT(SBN'*4/N/PI)  =     10.82 mm
                 Dreq =< 20             -> C5 = 3.0 mm
                 SBN = N*PI*(Dreq+C5)**2/4=     8396. mm2
 in BOLTING-UP : SBA = FDV/KSBE/PHI       =     3718. mm2

 BSR =PI*DT/N=  80.2 mm     BSX = 5*DL= 110.0 mm    BSMIN=  53.0 mm
 Fso = FDVX =   1462548. N
 Load to apply on bolting Fso/N =     26117. N
REAL BOLT STRESSES:
 FSBX/SBT =       68.9 MPa
 Fso/SB   =      116.0 MPa
```

Shell flange calculation GF02 (In Operation)

```
 DESIGN CODE    :  AD MERK – B8 and B7      MATERIALS:  FLANGE    / BOLTING
         P355NH                       25CrMo4
 DESIGN PRESSURE P =  0.580 MPa
 TEMPERATURE  =   167.0 ^0C                 NON CORRODED DIMENSIONS :
 CORROSION C2  = 3.0    mm                 DI = 1300.0 mm   DA = 1502.0 mm
 TOLERANCE TOL = 1.6    mm                 DT = 1430.0 mm   DD = 1332.0 mm
 ALLOWABLE STRESS DES. TEMP./AMB.          S1 =   16.0 mm   SF =   24.0 mm
 FLANGE (KS/KSE) : 165.5 MPa /  271.4 MPa  HF =   72.0 mm   HFJ=   67.0 mm
 BOLTS  (KSB/KSBE): 168.9 MPa /  338.5 MPa HA =  109.0 mm   DL =   22.0 mm
                                           DEJ= 1351.0 mm
 WEIGHT  :    260. kg
 BOLTS   : N= 56  DB= 20.0 mm    DFI=  16.93 mm
 GASKET : WIDTH  19.0 mm THICKNESS  4.0 mm GROOVES NBER  0.00
 SETTING: BD= 19.0 mm  K0=  0.0000 mm  KD =   0.0 MPa K0*KD=  380.00 N/mm
 AT TEMP: BD= 19.0 mm  K1= 20.9000 mm  KDT=   0.0 MPa
 FULL-FACE GASKET : NO
 DESIGN COEFF.    :  SD= 1.20
 BOLTS WITH MACHINED CONTACT SURFACE : YES -> PHI= 1.00
 INTEGRAL FLANGE WITH TAPERED HUB

 FEMALE SINGLE FLANGE COUPLING OF  5.00 mm
CORRODED VALUES   :
 DI= 1306.0 mm    S1=   13.0 mm    SF=   21.0 mm
 HA=  102.4 mm    HF=   65.4 mm

DESIGN PARAMETERS :
 V= 0.50    DLP=V*DL=      11.00 mm   B  = DA-DI-2*DLP.....=     174.00 mm
 SFC= MIN(SF,HF/3)..=      21.00 mm   SM = (SF+S1)/2.......=      17.00 mm
 B1 = (HA-HF)/HF....=  0.57   B0=(1+2*B1*SM/B)/(1+2*SM*(B1*B1+2*B1)/B)=0.87
 Z=(DI+SFC)*SFC*SFC.=    585207. mm^3  Z1=0.75*(DI+S1)*S1*S1=    167183. mm^3
 A  = (DT-DI-SFC)/2 =      51.50 mm   AB = (DT-DI-S1)/2....=      55.50 mm
 AD = (DT-DD)/2.....=      49.00 mm   ADB= (DT-DD)/2.......=      49.00 mm

DESIGN FOR BOLTING-UP CONDITION :
SECTION A-A :
 WAA=Fso*AD/KSE ............................=    264028. mm^3
 HFAA=SQRT(MAX(0,(1.27*WAA-Z)/B))...........=       0.00 mm
SECTION B-B :
 WBA=Fso*ADB/KSE ...........................=    264028. mm^3
 HFBA=B0*SQRT(MAX(0,(1.27*WBA-Z1)/B))........=      26.89 mm
DIN 2505 9.2  Flange deflection in the bolt circle   deltaF=     0.344 mm
                                           ATAN(deltaF/AD) =     0.402 ^0
DESIGN FOR SERVICE CONDITION :
SECTION A-A :
 WA=FSBX*A*/KS .............................=    270494. mm^3
 HFA=SQRT(MAX(0,(1.27*WA-Z)/B)).............=       0.00 mm
SECTION B-B :
 WB=FSBX*AB*/KS ............................=    291503. mm^3
 HFB=B0*SQRT(MAX(0,(1.27*WB-Z1)/B)).........=      29.55 mm

DIN 2505 9.2  Flange deflection in the bolt circle   deltaF=     0.237 mm
                                           ATAN(deltaF/AD) =     0.277 ^0

 HFMINI= MAX(HFAA,HFBA,HFA,HFB)+TOL.........=       31.2 mm
```

Shell flange calculation GF02 (In Test)

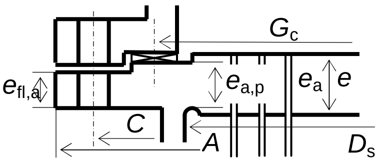
```
 DESIGN CODE    :  AD MERK – B8 and B7      MATERIALS:  FLANGE    / BOLTING
        P355NH                        25CrMo4
 DESIGN PRESSURE P =  0.859 MPa
 TEMPERATURE  =    20.0 °C                 NON CORRODED DIMENSIONS :
 CORROSION C2  = 3.0    mm                 DI = 1300.0 mm   DA = 1502.0 mm
 TOLERANCE TOL = 1.6    mm                 DT = 1430.0 mm   DD = 1332.0 mm
 ALLOWABLE STRESS DES. TEMP./AMB.          S1 =   16.0 mm   SF =   24.0 mm
 FLANGE (KS/KSE) : 271.4 MPa /  271.4 MPa  HF =   72.0 mm   HFJ=   67.0 mm
 BOLTS  (KSB/KSBE): 338.5 MPa /  338.5 MPa HA =  109.0 mm   DL =   22.0 mm
                                           DEJ= 1351.0 mm
 WEIGHT  :    260. kg
 BOLTS   : N= 56  DB= 20.0 mm    DFI=  16.93 mm
 GASKET : WIDTH  19.0 mm THICKNESS  4.0 mm GROOVES NBER  0.00
 SETTING: BD= 19.0 mm  K0=  0.0000 mm  KD =    0.0 MPa K0*KD=  380.00 N/mm
 AT TEMP: BD= 19.0 mm  K1= 20.9000 mm  KDT=    0.0 MPa
 FULL-FACE GASKET : NO
 DESIGN COEFF.    :  SD= 1.20
 BOLTS WITH MACHINED CONTACT SURFACE : YES -> PHI= 1.00
 INTEGRAL FLANGE WITH TAPERED HUB

 FEMALE SINGLE FLANGE COUPLING OF  5.00 mm
CORRODED VALUES   :
 DI= 1306.0 mm    S1=   13.0 mm    SF=   21.0 mm
 HA=  102.4 mm    HF=   65.4 mm

 BOLT LOADS :
 FRB=P*PI*DI*DI/4........= 1150719. N  FFB=P*PI*(DD*DD-DI*DI)/4=   46273. N
 FDB=P*PI*DD*SD*K1.......=   90152. N  FSP=FRB+FFB+FDB.........= 1287145. N
 FSPX=MAX(FSP)...........= 1287145. N
 ACTUAL BOLT CROSS-SECTION         :  SB  = N*PI/4*DFI**2 =     12611. mm2
 REQUIRED BOLT CROSS-SECTION       :  SBNE= FSP/KSB/PHI   =      3803. mm2
 BSR =PI*DT/N=  80.2 mm     BSX = 5*DL= 110.0 mm    BSMIN=  53.0 mm
REAL BOLT STRESSES:
 FSPX/SB  =      102.1 MPa
DESIGN PARAMETERS :
 V= 0.50    DLP=V*DL=      11.00 mm   B  = DA-DI-2*DLP.....=     174.00 mm
 SFC= MIN(SF,HF/3)..=      21.00 mm   SM = (SF+S1)/2.......=      17.00 mm
 B1 = (HA-HF)/HF....=  0.57   B0=(1+2*B1*SM/B)/(1+2*SM*(B1*B1+2*B1)/B)=0.87
 Z=(DI+SFC)*SFC*SFC.=    585207. mm3  Z1=0.75*(DI+S1)*S1*S1=    167183. mm3
 A  = (DT-DI-SFC)/2 =      51.50 mm   AB = (DT-DI-S1)/2....=      55.50 mm

DESIGN OF FLANGE THICKNESS :
SECTION A-A :
 WA=FSPX*A*/KSE.............................=    244218. mm3
 HFA=SQRT(MAX(0,(1.27*WA-Z)/B)).............=       0.00 mm
SECTION B-B :
 WB=FSPX*AB*/KSE............................=    263187. mm3
 HFB=B0*SQRT(MAX(0,(1.27*WB-Z1)/B)).........=      26.81 mm

DIN 2505 9.2  Flange deflection in the bolt circle   deltaF=     0.335 mm
                                           ATAN(deltaF/AD) =     0.391 °

 HFMINI= MAX(HFA,HFB)+TOL...................=       28.4 mm
```

Tubesheet(s) and Expansion Joint

Tubesheet, Loading conditions 1 [corroded normal condition] (Without expansion joint).

EN 13445:2002 V26 (2007-04) §[13.5]	Tubesheet		Tubes	Shell		Channel
	Tubeside	Shellside		far tubesheet	near tubesheet	
Pressure (MPa)	P_t=0.28	P_s=0.84				
Corrosion	c_t=3 mm	c_s=3 mm		3 mm	3 mm	3 mm
Material	P355NH		P355NL1	P355NL1	P355NL1	P355NL1
Temperature	400 °C		400 °C	400 °C		167 °C
Mean Metal Temp.			$t_{t,m}$=136 °C	$t_{s,m}$=177 °C		
Allowable stress	f = 111.3 MPa		f_t = 111.3 MPa	f_s = 134.7 MPa	$f_{s,1}$ = 134.7 MPa	f_c = 193.9 MPa
Modulus of elasticity	E = 170,000 MPa		E_t=193,840 MPa	E_s=190,840 MPa	$E_{s,1}$=190,840 MPa	E_c=191,640 MPa
Uncorroded thick.	**80 mm**		e_t=2.6 mm	16 mm	16 mm	16 mm
Diameter	A = 1,502 mm		d_t=25 mm	1,300 mm	1,300 mm	1,300 mm
Tolerance	1.6 mm					
Poisson's ratio	ν = 0.3		ν_t = 0.3	ν_s = 0.3		ν_c = 0.3

Pattern : Triangular	N_t=1320	OTL=1,274.23 mm	p=32 mm



Configuration b	e_s = 13 mm	e_c = 13 mm
D_s = 1,306 mm	C = 1,430 mm	e_a = 72.4 mm
D_c = 1,306 mm	G_c = 1,332 mm	$e_{a,p}$ = 67.4 mm
h_g = 0 mm	Flange face = 8 mm	$e_{fl,a}$ = 65.4 mm
Extra thickness (periphery):	Tubeside = 5 mm	Shellside = 0 mm

[13.7] Tubesheet properties	$e = e_a$	
Diameter of perforated region	$D_0 = 2r_0+d_t$	r_0 = 624.615 mm
Tube expansion depth ratio	$\rho = l_{t,x}/e = 0$	$l_{t,x}$ = 0 mm

Ligament efficiency : basic : $\mu = (p- d_t)/p = 0.219$ effective : $\mu^* = (p^* - d^*)/ p^* = 0.219$

$$p^* = \frac{p}{\sqrt{1-4\dfrac{\min[(S),(4D_0 \cdot p)]}{\pi \cdot D_0^2}}}$$

or if one unperforated lane and $U_L \le 4p$:

$$p^* = \frac{p}{\sqrt{1-\dfrac{4 \cdot U_L}{\pi \cdot D_0}}}$$

effective tube pitch : p^* = 32 mm

$d^* = \max[(d_t - 2e_t\ E_t/E\ f_t/f\ \rho),(d_t - 2e_t)]$= 25 mm

unperforated area : S = 0 mm²

center-to-center distance between rows : U_L = 0 mm

effective elastic constants E^* = 30,226.4 MPa ν^* = 0.433 (Fig. 13.7.8-1 , Fig. 13.7.8.-2)

Bending stiffness $D^* = (E^*.e^3)/(12(1-\nu^{*2}))$ = 1.176145×10⁹ N.mm

[13.8] Maximum allowable stress for tube-to-tubesheet joint

Welded tube-to-tubesheet joint : $f_{t,j} = \min[(f_{min}.a_t/e_t),f_t]$ (a_t = 2.6 mm) ($f_{min} = \min[f, f_t]$) f_{tj} = 111.3 MPa

[13.9] Maximum permissible buckling stress limit for tubes

$$f_{t,bk} = \frac{1}{x}\left[\sigma_{t,p} + \frac{R_p^t - |x \cdot \sigma_{t,p}|}{\sqrt{1+\left(\left((1+b_0)R_p^t - |x.\sigma_{t,p}|\right)/\sigma_{t,cr}\right)^2}}\right]$$

$f_{t,bk}$ shall be > 0

$$b_0 = 0{,}206\sqrt{\sigma_{t,cr}/R_p^t}\left(1-0{,}2\sqrt{\sigma_{t,cr}/R_p^t}\right)$$

$$\sigma_{t,p} = P_s d_t^2 - P_t(d_t - 2e_t)^2 / d_t^2 - (d_t - 2e_t)^2$$

$$\sigma_{t,cr} = \pi^2 E_t / l_{t,bk}^2 \cdot \left(d_t^2 + (d_t - 2e_t)^2\right)/16 = 121.61 \text{ MPa}$$

R_p^t = 167 MPa
x = 1.1
$l_{t,bk}$ = 1,000 mm

Parameters : F_q = 4.93 $F_{q,\infty}$ = 2.72 H = 5.35 H_∞ = 3.28 F_i = -0.477

[13.5.2] Conditions of applicability

$e_a \ge 0.75\ d_t$	$e_{a,p} \ge 0{,}8 e_a$	$U_L \le 4p$
$L \ge 2\times1.4\sqrt{(D_s+e_s)e_s}$	$D_0 \ge 0{,}85 D_e$	$0{,}9D_s \le G_c \le 1{,}2D_s$

The shell shall be cylindrical, uniform thickness e_s and similar material.

The distance between the expansion joint and the tubsheet shall be ≥ l_s ($l_s = 1.4\sqrt{(D_s+e_s)e_s}$ =183.33 mm).

[13.5.3] – Parameters

L = 4,726.2 mm | l_1 = 0 mm | l_1' = 0 mm

$D_e = (D_s + G_c)/2$ = 1,319 mm | k_c = 0 N

$h'_g = \max[(h_g - c_t),(0)]$ = 0 mm | $k_s = 2E_{s,1}\, e_{s,1}^{2,5} / [12(1-\nu_s^2)]^{0,75} / (D_s + e_{s,1})^{0,5}$ = 1,066,027 N

$K_t = \pi e_t (d_t - e_t) E_t / L$ = 7,504.17 N/mm | $x_s = 1 - N_t (d_t / D_e)^2$ = 0.526 | $X = (K_w / D^*)^{0,25} . D_e / 2$ = 6.949

$K_w = 8N_t . K_t / \pi / D_e^2$ = 14.5 N/mm³ | $x_t = 1 - N_t ((d_t - 2e_t)/D_e)^2$ = 0.703 | $Z = (k_s + k_c)/K_w^{0,25} / D^{*0,75}$ = 0.086

$K_s = \pi (D_s + e_s) / [(L - l_1 - l_1')/(e_s E_s) + (l_1 + l_1')/(e_{s,1} E_{s,1})]$=2,175,180 N/mm | K_J=/ | w_J = /

$K_{s,t} = K_s / (N_t . K_t)$ = 0.22 | $J = 1/(1 + K_s / K_J)$ = 1 | D_J = /

$\alpha_{s,m}(t_{s,m} - t_a)$=0.001902 mm/mm | $\alpha_{s,m,1}(t_{s,m} - t_a)$=0.001902 mm/mm | $\alpha_{t,m}(t_{t,m} - t_a)$=0.001367 mm/mm

$\gamma = [\alpha_{t,m} (t_{t,m} - t_a)\ L] - [\alpha_{s,m} (t_{s,m} - t_a) (L - l_1 - l_1') + \alpha_{s,m,1} (t_{s,m} - t_a) (l_1 + l_1')]$

[13.5.4.4] Effective pressure

$$P_e = \frac{J \cdot K_{s,t}}{1 + J \cdot K_{s,t} \cdot F_q}\left[\left[x_s + 2\nu_t(1 - x_s) + \frac{2\nu_s}{K_{s,t}} - \frac{1-J}{2J \cdot K_{s,t}}\,\frac{(D_J + 2w_j)^2 - D_S^2}{D_S^2}\right]P_S - \left[x_t + 2\nu_t(1 - x_t) + \frac{1}{J \cdot K_{s,t}}\right]P_t + \left[\frac{K_W}{2}\right]\gamma\right]$$

case	P_s (MPa)	P_t (MPa)	γ (mm)	P_e (MPa)
1	0.000	0.280	0.000	-0.160
2	0.840	0.000	0.000	0.314
3	0.840	0.280	0.000	0.153
4	0.000	0.000	-2.528	-1.931
5	0.000	0.280	-2.528	-2.092
6	0.840	0.000	-2.528	-1.618
7	0.840	0.280	-2.528	-1.778

[13.5.5] Tubesheet calculation

Bending stress : $\sigma = 1/(4\mu^* H).[D_e/(e-h'_g)]^2.P_e$ (with $e = e_a$) $|\sigma|$ shall be $\le \sigma_a$

Shear stress : $\tau = 1/(2\mu).D_0/(2e).P_e$ (with $e = e_{ap}$) $|\tau|$ shall be $\le \tau_a$

case	σ (MPa)	σ_a (MPa)	τ (MPa)	τ_a (MPa)
1	-11.379	1.5 f = 166.999	-3.466	0.8 f = 89.066
2	22.251	1.5 f = 166.999	6.777	0.8 f = 89.066
3	10.872	1.5 f = 166.999	3.311	0.8 f = 89.066
4	-137.007	2.25 f = 250.499	-41.729	0.8 f = 89.066
5	-148.386	2.25 f = 250.499	-45.195	0.8 f = 89.066
6	-114.756	2.25 f = 250.499	-34.952	0.8 f = 89.066
7	-126.135	2.25 f = 250.499	-38.418	0.8 f = 89.066

[13.5.6] Tubes calculation

Membrane stress :

Outer $\sigma_{t,0} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_q]$ $|\sigma_{t,0}|$ shall be $\le f_{t,j}$

If $\sigma_{t,0} < 0$ (tubes in compression) : $|\sigma_{t,0}|$ shall be $\le f_{t,bk}$

Inner $\sigma_{t,i} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_i]$ $|\sigma_{t,i}|$ shall be $\le f_{t,j}$

If $\sigma_{t,i} < 0$ (tubes in compression) : $|\sigma_{t,i}|$ shall be $\le f_{t,bk}$

Circumferential mean stress : $\sigma_{t,\theta} = [P_t(d_t - 2e_t) - P_s.d_t]/(2e_t)$

Radial mean stress : $\sigma_{t,r} = -(P_t + P_s)/2$

Total stress : $\sigma_{t,eq} = \max(|\sigma_{t,i} - \sigma_{t,\theta}|, |\sigma_{t,i} - \sigma_{t,r}|, |\sigma_{t,\theta} - \sigma_{t,r}|, |\sigma_{t,0} - \sigma_{t,\theta}|, |\sigma_{t,0} - \sigma_{t,r}|)$ $\sigma_{t,eq}$ shall be $\le \sigma_{t,a}$

case	$\sigma_{t,p}$ (MPa)	$\sigma_{t,0}$ (MPa)	$\sigma_{t,i}$ (MPa)	$f_{t,bk}$ (MPa)	$\sigma_{t,\theta}$ (MPa)	$\sigma_{t,r}$ (MPa)	$\sigma_{t,eq}$ (MPa)	$\sigma_{t,a}$ (MPa)
1	-0.471	3.364	-1.546	80.865	1.066	-0.140	3.504	f_t = 111.333
2	2.254	-6.256	3.345	83.223	-4.038	-0.420	7.384	f_t = 111.333
3	1.782	-2.892	1.800	82.849	-2.972	-0.560	4.772	f_t = 111.333
4	0.000	53.906	-5.212	81.432	0.000	0.000	53.906	1.5 f_t = 166.999
5	-0.471	57.270	-6.758	80.865	1.066	-0.140	57.410	1.5 f_t = 166.999
6	2.254	47.650	-1.867	83.223	-4.038	-0.420	51.689	1.5 f_t = 166.999
7	1.782	51.014	-3.413	82.849	-2.972	-0.560	53.987	1.5 f_t = 166.999

[13.5.7.1] Shell calculation (far from tubesheet)

Membrane stress :

$\sigma_{s,m} = D_s^2/(4e_s(D_s+e_s)).(P_t+P_e)$

Maximum permissible buckling stress limit :

$f_{s,bk} = K.e_s.E_s/4/(D_s+e_s)$ = 470.23 MPa (K=1) If $\sigma_{s,m} < 0$: $|\sigma_{s,m}|$ shall be $\leq f_{s,bk}$

Circumferential mean stress : $\sigma_{s,\theta} = P_s.D_s/2/e_s$

Radial mean stress : $\sigma_{s,r} = -P_s/2$

Total stress : $\sigma_{s,eq} = \max(|\sigma_{s,m} - \sigma_{s,\theta}|,|\sigma_{s,m} - \sigma_{s,r}|,|\sigma_{s,\theta} - \sigma_{s,r}|)$ $\sigma_{s,eq}$ shall be $\leq \sigma_{s,a}$

case	$\sigma_{s,m}$ (MPa)	$\sigma_{s,\theta}$ (MPa)	$\sigma_{s,r}$ (MPa)	$\sigma_{s,eq}$ (MPa)	$\sigma_{s,a}$ (MPa)
1	2.974	0.000	0.000	2.974	f_s = 134.667
2	7.800	42.194	-0.420	42.614	f_s = 134.667
3	10.774	42.194	-0.420	42.614	f_s = 134.667
4	-48.029	0.000	0.000	48.029	1.5 f_s = 202.001
5	-45.054	0.000	0.000	45.054	1.5 f_s = 202.001
6	-40.228	42.194	-0.420	82.422	1.5 f_s = 202.001
7	-37.254	42.194	-0.420	79.448	1.5 f_s = 202.001

[13.5.7.2] Shell calculation (tubesheet junction)

Membrane stress :

$\sigma_{s,m,1} = D_s^2/(4e_{s,1}(D_s+e_{s,1})).(P_t+P_e)$

Bending stress :

$\sigma_{s,b,1} = k_s/(k_s+k_c)(1/I_1)(D_e/2/e_{s,1})^2 P_e$ (with : $I_1 = H_\infty[(2F_{q,\infty}/X/Z)+(1-(1-\nu^*)/X/Z)]$= 29.982)

Total stress (only normal operating conditions) :

$\sigma_{s,eq,1} = \max(|\sigma_{s,m,1} - \sigma_{s,b,1} + P_s|,|\sigma_{s,m,1} + \sigma_{s,b,1}|)$ $\sigma_{s,eq,1}$ shall be $\leq \sigma_{s,a,1}$

case	$\sigma_{s,m,1}$ (MPa)	$\sigma_{s,b,1}$ (MPa)	$\sigma_{s,eq,1}$ (MPa)	$\sigma_{s,a,1}$ (MPa)
1	2.974	-13.769	16.743	3 $f_{s,1}$ = 404.001
2	7.800	26.925	34.725	3 $f_{s,1}$ = 404.001
3	10.774	13.156	23.930	3 $f_{s,1}$ = 404.001
4	-48.029	-165.784	213.813	3 $f_{s,1}$ = 404.001
5	-45.054	-179.553	224.608	3 $f_{s,1}$ = 404.001
6	-40.228	-138.860	179.088	3 $f_{s,1}$ = 404.001
7	-37.254	-152.629	189.883	3 $f_{s,1}$ = 404.001

[13.10] Tubesheet flanged extension :

$e_{fl,a}$ = 65.4 mm	P = 0.28 MPa	f = 111.3 MPa	f_A = 203.3 MPa
A = 1,502 mm	C = 1,430 mm	D_{ex} = 1,332 mm	G = 1,332 mm
$W = 0.1463\times10^7$ N	ν = 0.3	b = 0 mm	m = 1.2
$H = \pi/4\ G^2$ P	$H_D = \pi/4\ D_{ex}^2\ P$	$H_T = H - H_D$	H_G = 0.0000 N
$h_D = (C - D_{ex}) / 2$	$h_G = (C - G) / 2$	$h_T = (2\ C - D_{ex} - G) / 4$	
$M_{op} = H_D.h_D + H_T.h_T + H_G.h_G = 19.11844\times10^6$ N.mm		$M_A = W.h_G = 71.66483\times10^6$ N.mm	

Maximum radial stress : $\sigma_r = 12M/\left(\pi A\left[(1+\nu)+(1-\nu)(D_{ex}/A)^2\right]e_{fl,a}^2\right)$ $D_{ex} \leq G$

<u>Gasket seating</u> : σ_r = 23.03 MPa ($M = M_A$) σ_r shall be $\leq f_A$

<u>Operating condition</u> : σ_r = 6.14 MPa ($M = M_{op}$) σ_r shall be $\leq f$

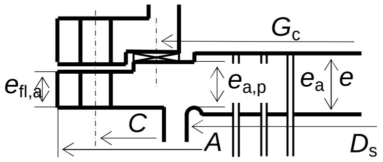
Error(s) and/or Warning(s)

The thickness is acceptable

Tubesheet, Loading conditions 2 [corroded normal condition] (Without expansion joint).

EN 13445:2002 V26 (2007-04) §[13.5]	Tubesheet		Tubes	Shell		Channel
	Tubeside	Shellside		far tubesheet	near tubesheet	
Pressure (MPa)	P_t=0.28	P_s=-0.103				
Corrosion	c_t=3 mm	c_s=3 mm		3 mm	3 mm	3 mm
Material	P355NH		P355NL1	P355NL1	P355NL1	P355NL1
Temperature	177 °C		177 °C	177 °C		167 °C
Mean Metal Temp.			$t_{t,m}$=136 °C	$t_{s,m}$=177 °C		
Allowable stress	f = 176.1 MPa		f_t = 178.9 MPa	f_s = 178.8 MPa	$f_{s,1}$ = 178.8 MPa	f_c = 193.9 MPa
Modulus of elasticity	E = 170,000 MPa		E_t=193,840 MPa	E_s=190,840 MPa	$E_{s,1}$=190,840 MPa	E_c=191,640 MPa
Uncorroded thick.	**80 mm**		e_t=2.6 mm	16 mm	16 mm	16 mm
Diameter	A = 1,502 mm		d_t=25 mm	1,300 mm	1,300 mm	1,300 mm
Tolerance	1.6 mm					
Poisson's ratio	ν = 0.3		ν_t = 0.3	ν_s = 0.3		ν_c = 0.3

Pattern : Triangular	N_t=1320	OTL=1,274.23 mm	p=32 mm



Configuration b	e_s = 13 mm	e_c = 13 mm
D_s = 1,306 mm	C = 1,430 mm	e_a = 72.4 mm
D_c = 1,306 mm	G_c = 1,332 mm	$e_{a,p}$ = 67.4 mm
h_g = 0 mm	Flange face = 8 mm	$e_{fl,a}$ = 65.4 mm
Extra thickness (periphery):	Tubeside = 5 mm	Shellside = 0 mm

[13.7] Tubesheet properties	$e = e_a$	
Diameter of perforated region	$D_0 = 2r_0+d_t$	r_0 = 624.615 mm
Tube expansion depth ratio	$\rho = l_{t,x}/e = 0$	$l_{t,x}$ = 0 mm

Ligament efficiency : basic : $\mu = (p- d_t)/p$ = 0.219

$$p^* = \frac{p}{\sqrt{1-4\dfrac{\min[(S),(4D_0\cdot p)]}{\pi\cdot D_0^2}}}$$

or if one unperforated lane and $U_L \le 4p$:

$$p^* = \frac{p}{\sqrt{1-\dfrac{4\cdot U_L}{\pi\cdot D_0}}}$$

effective : $\mu^* = (p^* - d^*)/ p^*$ = 0.219

effective tube pitch : p^* = 32 mm

$d^* = \max[(d_t - 2e_t\ E_t/E\ f_t/f\ \rho),(d_t - 2e_t)]$ = 25 mm

unperforated area : S = 0 mm²

center-to-center distance between rows : U_L = 0 mm

effective elastic constants	E^* = 30,226.4 MPa ν^* = 0.433	(Fig. 13.7.8-1 , Fig. 13.7.8.-2)
Bending stiffness	$D^* = (E^*.e^3)/(12(1-\nu^{*2}))$ = 1.176145×10^9 N.mm	

[13.8] Maximum allowable stress for tube-to-tubesheet joint
Welded tube-to-tubesheet joint : $f_{t,j} = \min[(f_{min}.a_t/e_t),f_t]$ (a_t = 2.6 mm)   ($f_{min} = \min[f, f_t]$) f_{tj} = 176.1 MPa

[13.9] Maximum permissible buckling stress limit for tubes

$$f_{t,bk} = \frac{1}{x}\left[\sigma_{t,p} + \frac{R_p^t - |x\cdot\sigma_{t,p}|}{\sqrt{1+\left(\left((1+b_0)R_p^t - |x.\sigma_{t,p}|\right)/\sigma_{t,cr}\right)^2}}\right]$$

$f_{t,bk}$ shall be > 0

$$b_0 = 0{,}206\sqrt{\sigma_{t,cr}/R_p^t}\left(1-0{,}2\sqrt{\sigma_{t,cr}/R_p^t}\right)$$

$$\sigma_{t,p} = P_s d_t^2 - P_t(d_t-2e_t)^2 / d_t^2 - (d_t-2e_t)^2$$

$$\sigma_{t,cr} = \pi^2 E_t / l_{t,bk}^2 \cdot \left(d_t^2 + (d_t - 2e_t)^2\right)/16 = 121.61 \text{ MPa}$$

R_p^t = 268.34 MPa

x = 1.1

$l_{t,bk}$ = 1,000 mm

Parameters :	F_q = 4.93	$F_{q,\infty}$ = 2.72	H = 5.35	H_∞ = 3.28	F_i = -0.477

[13.5.2] Conditions of applicability

$e_a \ge 0.75\ d_t$	$e_{a,p} \ge 0{,}8e_a$	$U_L \le 4p$
$L \ge 2\times 1.4\sqrt{(D_s+e_s)e_s}$	$D_0 \ge 0{,}85D_e$	$0{,}9D_s \le G_c \le 1{,}2D_s$

The shell shall be cylindrical, uniform thickness e_s and similar material.

The distance between the expansion joint and the tubsheet shall be ≥ l_s ($l_s = 1.4\sqrt{(D_s+e_s)e_s}$ =183.33 mm).

[13.5.3] – Parameters

L = 4,726.2 mm | l_1 = 0 mm | l_1' = 0 mm

$D_e = (D_s + G_c)/2$ = 1,319 mm | k_c = 0 N

$h'_g = \max[(h_g - c_t),(0)]$ = 0 mm | $k_s = 2E_{s,1}\, e_{s,1}^{2,5} / [12(1-\nu_s^2)]^{0,75} / (D_s + e_{s,1})^{0,5}$ = 1,066,027 N

$K_t = \pi e_t (d_t - e_t) E_t / L$ = 7,504.17 N/mm | $x_s = 1 - N_t (d_t / D_e)^2$ = 0.526 | $X = (K_w / D^*)^{0,25} . D_e / 2$ = 6.949

$K_w = 8N_t . K_t / \pi / D_e^2$ = 14.5 N/mm³ | $x_t = 1 - N_t ((d_t - 2e_t)/D_e)^2$ = 0.703 | $Z = (k_s + k_c)/K_w^{0,25} / D^{*0,75}$ = 0.086

$K_s = \pi (D_s + e_s) / [(L - l_1 - l_1')/(e_s E_s) + (l_1 + l_1')/(e_{s,1} E_{s,1})]$=2,175,180 N/mm | K_J=/ | w_J = /

$K_{s,t} = K_s / (N_t . K_t)$= 0.22 | $J = 1/(1 + K_s / K_J)$ = 1 | D_J = /

$\alpha_{s,m}(t_{s,m} - t_a)$=0.001902 mm/mm | $\alpha_{s,m,1}(t_{s,m} - t_a)$=0.001902 mm/mm | $\alpha_{t,m}(t_{t,m} - t_a)$=0.001367 mm/mm

$\gamma = [\alpha_{t,m}(t_{t,m} - t_a)\ L] - [\alpha_{s,m}(t_{s,m} - t_a)(L - l_1 - l_1') + \alpha_{s,m,1}(t_{s,m} - t_a)(l_1 + l_1')]$

[13.5.4.4] Effective pressure

$$P_e = \frac{J \cdot K_{s,t}}{1 + J \cdot K_{s,t} \cdot F_q}\left[\left[x_s + 2\nu_t(1-x_s) + \frac{2\nu_s}{K_{s,t}} - \frac{1-J}{2J \cdot K_{s,t}}\frac{(D_J + 2w_j)^2 - D_S^2}{D_S^2}\right]P_S - \left[x_t + 2\nu_t(1-x_t) + \frac{1}{J \cdot K_{s,t}}\right]P_t + \left[\frac{K_W}{2}\right]\gamma\right]$$

case	P_s (MPa)	P_t (MPa)	γ (mm)	P_e (MPa)
1	0.000	0.280	0.000	-0.160
2	-0.103	0.000	0.000	-0.038
3	-0.103	0.280	0.000	-0.199
4	0.000	0.000	-2.528	-1.931
5	0.000	0.280	-2.528	-2.092
6	-0.103	0.000	-2.528	-1.970
7	-0.103	0.280	-2.528	-2.130

[13.5.5] Tubesheet calculation

Bending stress : $\sigma = 1/(4\mu^* H).[D_e/(e - h'_g)]^2.P_e$ (with $e = e_a$) $|\sigma|$ shall be ≤ σ_a

Shear stress : $\tau = 1/(2\mu).D_0/(2e).P_e$ (with $e = e_{ap}$) $|\tau|$ shall be ≤ τ_a

case	σ (MPa)	σ_a (MPa)	τ (MPa)	τ_a (MPa)
1	-11.379	1.5 f = 264.199	-3.466	0.8 f = 140.906
2	-2.728	1.5 f = 264.199	-0.831	0.8 f = 140.906
3	-14.107	1.5 f = 264.199	-4.297	0.8 f = 140.906
4	-137.007	2.25 f = 396.299	-41.729	0.8 f = 140.906
5	-148.386	2.25 f = 396.299	-45.195	0.8 f = 140.906
6	-139.736	2.25 f = 396.299	-42.560	0.8 f = 140.906
7	-151.114	2.25 f = 396.299	-46.026	0.8 f = 140.906

[13.5.6] Tubes calculation

Membrane stress :

Outer $\sigma_{t,0} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_q]$ $|\sigma_{t,0}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,0}$ < 0 (tubes in compression) : $|\sigma_{t,0}|$ shall be ≤ $f_{t,bk}$

Inner $\sigma_{t,i} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_i]$ $|\sigma_{t,i}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,i}$ < 0 (tubes in compression) : $|\sigma_{t,i}|$ shall be ≤ $f_{t,bk}$

Circumferential mean stress : $\sigma_{t,\theta} = [P_t(d_t - 2e_t) - P_s.d_t]/(2e_t)$

Radial mean stress : $\sigma_{t,r} = -(P_t + P_s)/2$

Total stress : $\sigma_{t,eq} = \max(|\sigma_{t,i} - \sigma_{t,\theta}|, |\sigma_{t,i} - \sigma_{t,r}|, |\sigma_{t,\theta} - \sigma_{t,r}|, |\sigma_{t,0} - \sigma_{t,\theta}|, |\sigma_{t,0} - \sigma_{t,r}|)$ $\sigma_{t,eq}$ shall be ≤ $\sigma_{t,a}$

case	$\sigma_{t,p}$ (MPa)	$\sigma_{t,0}$ (MPa)	$\sigma_{t,i}$ (MPa)	$f_{t,bk}$ (MPa)	$\sigma_{t,\theta}$ (MPa)	$\sigma_{t,r}$ (MPa)	$\sigma_{t,eq}$ (MPa)	$\sigma_{t,a}$ (MPa)
1	-0.471	3.364	-1.546	90.988	1.066	-0.140	3.504	f_t = 178.893
2	-0.276	0.767	-0.410	91.200	0.495	0.052	0.905	f_t = 178.893
3	-0.748	4.131	-1.956	90.687	1.561	-0.089	4.220	f_t = 178.893
4	0.000	53.906	-5.212	91.500	0.000	0.000	53.906	1.5 f_t = 268.340
5	-0.471	57.270	-6.758	90.988	1.066	-0.140	57.410	1.5 f_t = 268.340
6	-0.276	54.673	-5.623	91.200	0.495	0.052	54.622	1.5 f_t = 268.340
7	-0.748	58.037	-7.168	90.687	1.561	-0.089	58.126	1.5 f_t = 268.340

[13.5.7.1] Shell calculation (far from tubesheet)

Membrane stress :

$\sigma_{s,m} = D_s^2/(4e_s(D_s+e_s)).(P_t+P_e)$

Maximum permissible buckling stress limit :

$f_{s,bk} = K.e_s.E_s/4/(D_s+e_s)$ = 470.23 MPa (K=1) If $\sigma_{s,m} < 0$: $|\sigma_{s,m}|$ shall be ≤ $f_{s,bk}$

Circumferential mean stress : $\sigma_{s,\theta} = P_s.D_s/2/e_s$

Radial mean stress : $\sigma_{s,r} = -P_s/2$

Total stress : $\sigma_{s,eq} = \max(|\sigma_{s,m} - \sigma_{s,\theta}|,|\sigma_{s,m} - \sigma_{s,r}|,|\sigma_{s,\theta} - \sigma_{s,r}|)$ $\sigma_{s,eq}$ shall be ≤ $\sigma_{s,a}$

case	$\sigma_{s,m}$ (MPa)	$\sigma_{s,\theta}$ (MPa)	$\sigma_{s,r}$ (MPa)	$\sigma_{s,eq}$ (MPa)	$\sigma_{s,a}$ (MPa)
1	2.974	0.000	0.000	2.974	f_s = 178.775
2	-0.956	-5.174	0.052	5.225	f_s = 178.775
3	2.018	-5.174	0.052	7.191	f_s = 178.775
4	-48.029	0.000	0.000	48.029	1.5 f_s = 268.163
5	-45.054	0.000	0.000	45.054	1.5 f_s = 268.163
6	-48.985	-5.174	0.052	49.036	1.5 f_s = 268.163
7	-46.011	-5.174	0.052	46.062	1.5 f_s = 268.163

[13.5.7.2] Shell calculation (tubesheet junction)

Membrane stress :

$\sigma_{s,m,1} = D_s^2/(4e_{s,1}(D_s+e_{s,1})).(P_t+P_e)$

Bending stress :

$\sigma_{s,b,1} = k_s/(k_s+k_c)(1/I_1)(D_e/2/e_{s,1})^2P_e$ (with : $I_1 = H_\infty[(2F_{q,\infty}/X/Z)+(1-(1-\nu^*)/X/Z)]$= 29.982)

Total stress (only normal operating conditions) :

$\sigma_{s,eq,1} = \max(|\sigma_{s,m,1} - \sigma_{s,b,1} + P_s|,|\sigma_{s,m,1} + \sigma_{s,b,1}|)$ $\sigma_{s,eq,1}$ shall be ≤ $\sigma_{s,a,1}$

case	$\sigma_{s,m,1}$ (MPa)	$\sigma_{s,b,1}$ (MPa)	$\sigma_{s,eq,1}$ (MPa)	$\sigma_{s,a,1}$ (MPa)
1	2.974	-13.769	16.743	3 $f_{s,1}$ = 536.325
2	-0.956	-3.301	4.258	3 $f_{s,1}$ = 536.325
3	2.018	-17.070	18.985	3 $f_{s,1}$ = 536.325
4	-48.029	-165.784	213.813	3 $f_{s,1}$ = 536.325
5	-45.054	-179.553	224.608	3 $f_{s,1}$ = 536.325
6	-48.985	-169.086	218.071	3 $f_{s,1}$ = 536.325
7	-46.011	-182.855	228.865	3 $f_{s,1}$ = 536.325

[13.10] Tubesheet flanged extension :

$e_{fl,a}$ = 65.4 mm	P = 0.28 MPa	f = 176.1 MPa	f_A = 203.3 MPa
A = 1,502 mm	C = 1,430 mm	D_{ex} = 1,332 mm	G = 1,332 mm
$W = 0.1463\times10^7$ N	ν = 0.3	b = 0 mm	m = 1.2
$H = \pi/4\ G^2$ P	$H_D = \pi/4\ D_{ex}^2\ P$	$H_T = H - H_D$	H_G = 0.0000 N
$h_D = (C - D_{ex})/2$	$h_G = (C - G)/2$	$h_T = (2\ C - D_{ex} - G)/4$	

$M_{op} = H_D.h_D + H_T.h_T + H_G.h_G = 19.11844\times10^6$ N.mm $M_A = W.h_G = 71.66483\times10^6$ N.mm

Maximum radial stress : $\sigma_r = 12M/\left(\pi A\left[(1+\nu)+(1-\nu)(D_{ex}/A)^2\right]e_{fl,a}^2\right)$ $D_{ex} \le G$

Gasket seating : σ_r = 23.03 MPa ($M = M_A$) σ_r shall be ≤ f_A

Operating condition : σ_r = 6.14 MPa ($M = M_{op}$) σ_r shall be ≤ f

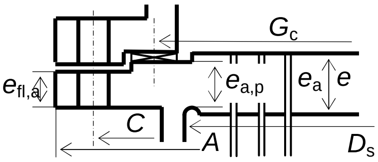
Error(s) and/or Warning(s)

The thickness is acceptable

Tubesheet, Loading conditions 3 [corroded normal condition] (Without expansion joint).

EN 13445:2002 V26 (2007-04) §[13.5]	Tubesheet		Tubes	Shell		Channel
	Tubeside	Shellside		far tubesheet	near tubesheet	
Pressure (MPa)	P_t=-0.103	P_s=0.84				
Corrosion	c_t=3 mm	c_s=3 mm		3 mm	3 mm	3 mm
Material	P355NH		P355NL1	P355NL1	P355NL1	P355NL1
Temperature	400 °C		400 °C	400 °C		167 °C
Mean Metal Temp.			$t_{t,m}$=167 °C	$t_{s,m}$=177 °C		
Allowable stress	f = 111.3 MPa		f_t = 111.3 MPa	f_s = 134.7 MPa	$f_{s,1}$ = 134.7 MPa	f_c = 181.8 MPa
Modulus of elasticity	E = 188,600 MPa		E_t=191,640 MPa	E_s=190,840 MPa	$E_{s,1}$=190,840 MPa	E_c=191,640 MPa
Uncorroded thick.	**80 mm**		e_t=2.6 mm	16 mm	16 mm	16 mm
Diameter	A = 1,502 mm		d_t=25 mm	1,300 mm	1,300 mm	1,300 mm
Tolerance	1.6 mm					
Poisson's ratio	ν = 0.3		ν_t = 0.3	ν_s = 0.3		ν_c = 0.3

Pattern : Triangular	N_t=1320	OTL=1,274.23 m m	p=32 mm



Configuration b	e_s = 13 mm	e_c = 13 mm
D_s = 1,306 mm	C = 1,430 mm	e_a = 72.4 mm
D_c = 1,306 mm	G_c = 1,332 mm	$e_{a,p}$ = 67.4 mm
h_g = 0 mm	Flange face = 8 mm	$e_{fl,a}$ = 65.4 mm
Extra thickness (periphery):	Tubeside = 5 mm	Shellside = 0 mm

[13.7] Tubesheet properties — $e = e_a$

Diameter of perforated region — $D_0 = 2r_0+d_t$ — r_0 = 624.615 mm

Tube expansion depth ratio — $\rho = l_{t,x}/e = 0$ — $l_{t,x}$ = 0 mm

Ligament efficiency : basic : $\mu = (p- d_t)/p$ = 0.219 — effective : $\mu^* = (p^* - d^*)/ p^*$ = 0.219

$$p^* = \frac{p}{\sqrt{1-4\frac{\min[(S),(4D_0\cdot p)]}{\pi\cdot D_0^2}}}$$

or if one unperforated lane and $U_L \le 4p$:

$$p^* = \frac{p}{\sqrt{1-\frac{4\cdot U_L}{\pi\cdot D_0}}}$$

effective tube pitch : p^* = 32 mm

$d^* = \max[(d_t -2e_t\ E_t/E\ f_t/f\ \rho),(d_t -2e_t)]$= 25 mm

unperforated area : S = 0 mm²

center-to-center distance between rows : U_L = 0 mm

effective elastic constants — E^* = 33,533.5 MPa — ν^* = 0.433 — (Fig. 13.7.8-1 , Fig. 13.7.8.-2)

Bending stiffness — $D^* = (E^*.e^3)/(12(1-\nu^{*2}))$ = 1.304829×10⁹ N.mm

[13.8] Maximum allowable stress for tube-to-tubesheet joint

Welded tube-to-tubesheet joint : $f_{t,j} = \min[(f_{min}.a_t/e_t),f_t]$ (a_t = 2.6 mm) ($f_{min} = \min[f, f_t]$) f_{tj} = 111.3 MPa

[13.9] Maximum permissible buckling stress limit for tubes

$$f_{t,bk} = \frac{1}{x}\left[\sigma_{t,p} + \frac{R_p^t - |x\cdot\sigma_{t,p}|}{\sqrt{1+\left(\left((1+b_0)R_p^t - |x.\sigma_{t,p}|\right)/\sigma_{t,cr}\right)^2}}\right]$$

$f_{t,bk}$ shall be > 0

$$b_0 = 0{,}206\sqrt{\sigma_{t,cr}/R_p^t}\left(1-0{,}2\sqrt{\sigma_{t,cr}/R_p^t}\right)$$

$$\sigma_{t,p} = P_s d_t^2 - P_t(d_t-2e_t)^2 / d_t^2 - (d_t-2e_t)^2$$

$$\sigma_{t,cr} = \pi^2 E_t / l_{t,bk}^2 \cdot \left(d_t^2 + (d_t-2e_t)^2\right)/16 = 120.23 \text{ MPa}$$

R^t_p = 167 MPa

x = 1.1

$l_{t,bk}$ = 1,000 mm

Parameters : F_q = 4.82 — $F_{q,\infty}$ = 2.65 — H = 5.15 — H_∞ = 3.19 — F_i = -0.479

[13.5.2] Conditions of applicability

$e_a \ge 0.75\ d_t$	$e_{a,p} \ge 0{,}8e_a$	$U_L \le 4p$
$L \ge 2\times1.4\sqrt{(D_s+e_s)e_s}$	$D_0 \ge 0{,}85D_e$	$0{,}9D_s \le G_c \le 1{,}2D_s$

The shell shall be cylindrical, uniform thickness e_s and similar material.

The distance between the expansion joint and the tubsheet shall be ≥ l_s ($l_s = 1.4\sqrt{(D_s+e_s)e_s}$ =183.33 mm).

[13.5.3] – Parameters

L = 4,726.2 mm — l_1 = 0 mm — l_1' = 0 mm

$D_e = (D_s + G_c)/2$ = 1,319 mm — k_c = 0 N

$h'_g = \max[(h_g - c_t),(0)]$ = 0 mm — $k_s = 2E_{s,1}\, e_{s,1}^{2,5} / [12(1-\nu_s^2)]^{0,75} / (D_s + e_{s,1})^{0,5}$ = 1,066,027 N

$K_t = \pi e_t (d_t - e_t) E_t / L$ = 7,419 N/mm — $x_s = 1 - N_t (d_t / D_e)^2$ = 0.526 — $X = (K_w / D^*)^{0,25} . D_e / 2$ = 6.752

$K_w = 8 N_t . K_t / \pi / D_e^2$ = 14.33 N/mm³ — $x_t = 1 - N_t ((d_t - 2e_t)/D_e)^2$ = 0.703 — $Z = (k_s + k_c)/K_w^{0,25} / D^{*0,75}$ = 0.08

$K_s = \pi (D_s + e_s) / [(L - l_1 - l_1')/(e_s E_s) + (l_1 + l_1')/(e_{s,1} E_{s,1})]$=2,175,180 N/mm — K_J=/ — w_J = /

$K_{s,t} = K_s / (N_t . K_t)$= 0.222 — $J = 1/(1 + K_s / K_J)$ = 1 — D_J = /

$\alpha_{s,m}(t_{s,m} - t_a)$=0.001902 mm/mm — $\alpha_{s,m,1}(t_{s,m} - t_a)$=0.001902 mm/mm — $\alpha_{t,m}(t_{t,m} - t_a)$=0.001769 mm/mm

$\gamma = [\alpha_{t,m} (t_{t,m} - t_a)\; L] - [\alpha_{s,m} (t_{s,m} - t_a)(L - l_1 - l_1') + \alpha_{s,m,1} (t_{s,m} - t_a)(l_1 + l_1')]$

[13.5.4.4] Effective pressure

$$P_e = \frac{J \cdot K_{s,t}}{1 + J \cdot K_{s,t} \cdot F_q}\left[\left[x_s + 2\nu_t(1-x_s) + \frac{2\nu_s}{K_{s,t}} - \frac{1-J}{2J \cdot K_{s,t}}\frac{(D_J + 2w_j)^2 - D_S^2}{D_S^2}\right]P_S - \left[x_t + 2\nu_t(1-x_t) + \frac{1}{J \cdot K_{s,t}}\right]P_t + \left[\frac{K_W}{2}\right]\gamma\right]$$

case	P_s (MPa)	P_t (MPa)	γ (mm)	P_e (MPa)
1	0.000	-0.103	0.000	0.059
2	0.840	0.000	0.000	0.316
3	0.840	-0.103	0.000	0.376
4	0.000	0.000	-0.628	-0.483
5	0.000	-0.103	-0.628	-0.424
6	0.840	0.000	-0.628	-0.167
7	0.840	-0.103	-0.628	-0.107

[13.5.5] Tubesheet calculation

Bending stress : $\sigma = 1/(4\mu^* H).[D_e/(e - h'_g)]^2.P_e$ (with $e = e_a$) $|\sigma|$ shall be ≤ σ_a

Shear stress : $\tau = 1/(2\mu).D_0/(2e).P_e$ (with $e = e_{ap}$) $|\tau|$ shall be ≤ τ_a

case	σ (MPa)	σ_a (MPa)	τ (MPa)	τ_a (MPa)
1	4.384	1.5 f = 166.999	1.285	0.8 f = 89.066
2	23.324	1.5 f = 166.999	6.837	0.8 f = 89.066
3	27.708	1.5 f = 166.999	8.122	0.8 f = 89.066
4	-35.601	2.25 f = 250.499	-10.436	0.8 f = 89.066
5	-31.217	2.25 f = 250.499	-9.151	0.8 f = 89.066
6	-12.277	2.25 f = 250.499	-3.599	0.8 f = 89.066
7	-7.892	2.25 f = 250.499	-2.314	0.8 f = 89.066

[13.5.6] Tubes calculation

Membrane stress :

Outer $\sigma_{t,0} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_q]$ $|\sigma_{t,0}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,0} < 0$ (tubes in compression) : $|\sigma_{t,0}|$ shall be ≤ $f_{t,bk}$

Inner $\sigma_{t,i} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_i]$ $|\sigma_{t,i}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,i} < 0$ (tubes in compression) : $|\sigma_{t,i}|$ shall be ≤ $f_{t,bk}$

Circumferential mean stress : $\sigma_{t,\theta} = [P_t(d_t - 2e_t) - P_s.d_t]/(2e_t)$

Radial mean stress : $\sigma_{t,r} = -(P_t + P_s)/2$

Total stress : $\sigma_{t,eq} = \max(|\sigma_{t,i} - \sigma_{t,\theta}|,|\sigma_{t,i} - \sigma_{t,r}|,|\sigma_{t,\theta} - \sigma_{t,r}|,|\sigma_{t,0} - \sigma_{t,\theta}|,|\sigma_{t,0} - \sigma_{t,r}|)$ $\sigma_{t,eq}$ shall be ≤ $\sigma_{t,a}$

case	$\sigma_{t,p}$ (MPa)	$\sigma_{t,0}$ (MPa)	$\sigma_{t,i}$ (MPa)	$f_{t,bk}$ (MPa)	$\sigma_{t,\theta}$ (MPa)	$\sigma_{t,r}$ (MPa)	$\sigma_{t,eq}$ (MPa)	$\sigma_{t,a}$ (MPa)
1	0.173	-1.212	0.571	80.943	-0.392	0.052	1.264	f_t = 111.333
2	2.254	-6.130	3.357	82.603	-4.038	-0.420	7.395	f_t = 111.333
3	2.427	-7.342	3.927	82.741	-4.431	-0.368	8.358	f_t = 111.333
4	0.000	13.170	-1.310	80.804	0.000	0.000	13.170	1.5 f_t = 166.999
5	0.173	11.958	-0.739	80.943	-0.392	0.052	12.350	1.5 f_t = 166.999
6	2.254	7.040	2.047	82.603	-4.038	-0.420	11.079	1.5 f_t = 166.999
7	2.427	5.828	2.618	82.741	-4.431	-0.368	10.259	1.5 f_t = 166.999

[13.5.7.1] Shell calculation (far from tubesheet)

Membrane stress :

$\sigma_{s,m} = D_s^2/(4e_s(D_s+e_s)).(P_t+P_e)$

Maximum permissible buckling stress limit :

$f_{s,bk} = K.e_s.E_s/4/(D_s+e_s)$ = 470.23 MPa (K=1)   If $\sigma_{s,m} < 0$: $|\sigma_{s,m}|$ shall be $\leq f_{s,bk}$

Circumferential mean stress : $\sigma_{s,\theta} = P_s.D_s/2/e_s$

Radial mean stress : $\sigma_{s,r} = -P_s/2$

Total stress : $\sigma_{s,eq} = \max(|\sigma_{s,m}-\sigma_{s,\theta}|,|\sigma_{s,m}-\sigma_{s,r}|,|\sigma_{s,\theta}-\sigma_{s,r}|)$ $\sigma_{s,eq}$ shall be $\leq \sigma_{s,a}$

case	$\sigma_{s,m}$ (MPa)	$\sigma_{s,\theta}$ (MPa)	$\sigma_{s,r}$ (MPa)	$\sigma_{s,eq}$ (MPa)	$\sigma_{s,a}$ (MPa)
1	-1.082	0.000	0.000	1.082	f_s = 134.667
2	7.869	42.194	-0.420	42.614	f_s = 134.667
3	6.787	42.194	-0.420	42.614	f_s = 134.667
4	-12.011	0.000	0.000	12.011	1.5 f_s = 202.001
5	-13.093	0.000	0.000	13.093	1.5 f_s = 202.001
6	-4.142	42.194	-0.420	46.336	1.5 f_s = 202.001
7	-5.224	42.194	-0.420	47.418	1.5 f_s = 202.001

[13.5.7.2] Shell calculation (tubesheet junction)

Membrane stress :

$\sigma_{s,m,1} = D_s^2/(4e_{s,1}(D_s+e_{s,1})).(P_t+P_e)$

Bending stress :

$\sigma_{s,b,1} = k_s/(k_s+k_c)(1/I_1)(D_e/2/e_{s,1})^2 P_e$ (with : $I_1 = H_\infty[(2F_{q,\infty}/X/Z)+(1-(1-\nu^*)/X/Z)]$= 31.144)

Total stress (only normal operating conditions) :

$\sigma_{s,eq,1} = \max(|\sigma_{s,m,1}-\sigma_{s,b,1}+P_s|,|\sigma_{s,m,1}+\sigma_{s,b,1}|)$ $\sigma_{s,eq,1}$ shall be $\leq \sigma_{s,a,1}$

case	$\sigma_{s,m,1}$ (MPa)	$\sigma_{s,b,1}$ (MPa)	$\sigma_{s,eq,1}$ (MPa)	$\sigma_{s,a,1}$ (MPa)
1	-1.082	4.915	5.997	3 $f_{s,1}$ = 404.001
2	7.869	26.149	34.018	3 $f_{s,1}$ = 404.001
3	6.787	31.064	37.851	3 $f_{s,1}$ = 404.001
4	-12.011	-39.912	51.923	3 $f_{s,1}$ = 404.001
5	-13.093	-34.997	48.090	3 $f_{s,1}$ = 404.001
6	-4.142	-13.763	17.905	3 $f_{s,1}$ = 404.001
7	-5.224	-8.848	14.072	3 $f_{s,1}$ = 404.001

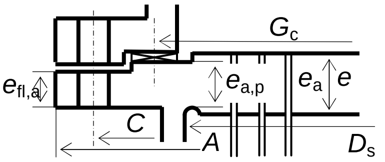
Error(s) and/or Warning(s)

The thickness is acceptable

Tubesheet, Loading conditions 4 [corroded normal condition] (Without expansion joint).

EN 13445:2002 V26 (2007-04) §[13.5]	Tubesheet		Tubes	Shell		Channel
	Tubeside	Shellside		far tubesheet	near tubesheet	
Pressure (MPa)	P_t=0.28	P_s=0.1				
Corrosion	c_t=3 mm	c_s=3 mm		3 mm	3 mm	3 mm
Material	P355NH		P355NL1	P355NL1	P355NL1	P355NL1
Temperature	400 °C		400 °C	400 °C		167 °C
Mean Metal Temp.			$t_{t,m}$=163 °C	$t_{s,m}$=204 °C		
Allowable stress	f = 111.3 MPa		f_t = 111.3 MPa	f_s = 134.7 MPa	$f_{s,1}$ = 134.7 MPa	f_c = 193.9 MPa
Modulus of elasticity	E = 170,000 MPa		E_t=191,960 MPa	E_s=188,840 MPa	$E_{s,1}$=188,840 MPa	E_c=191,640 MPa
Uncorroded thick.	**80 mm**		e_t=2.6 mm	16 mm	16 mm	16 mm
Diameter	A = 1,502 mm		d_t=25 mm	1,300 mm	1,300 mm	1,300 mm
Tolerance	1.6 mm					
Poisson's ratio	ν = 0.3		ν_t = 0.3	ν_s = 0.3		ν_c = 0.3

Pattern : Triangular	N_t=1320	OTL=1,274.23 mm	p=32 mm



Configuration b	e_s = 13 mm	e_c = 13 mm
D_s = 1,306 mm	C = 1,430 mm	e_a = 72.4 mm
D_c = 1,306 mm	G_c = 1,332 mm	$e_{a,p}$ = 67.4 mm
h_g = 0 mm	Flange face = 8 mm	$e_{fl,a}$ = 65.4 mm
Extra thickness (periphery):	Tubeside = 5 mm	Shellside = 0 mm

[13.7] Tubesheet properties	$e = e_a$	
Diameter of perforated region	$D_0 = 2r_0 + d_t$	r_0 = 624.615 mm
Tube expansion depth ratio	$\rho = l_{t,x}/e = 0$	$l_{t,x}$ = 0 mm

Ligament efficiency : basic : $\mu = (p - d_t)/p$ = 0.219

$$p^* = \frac{p}{\sqrt{1 - 4\frac{\min[(S),(4D_0 \cdot p)]}{\pi \cdot D_0^2}}}$$

or if one unperforated lane and $U_L \leq 4p$:

$$p^* = \frac{p}{\sqrt{1 - \frac{4 \cdot U_L}{\pi \cdot D_0}}}$$

effective : $\mu^* = (p^* - d^*)/p^*$ = 0.219

effective tube pitch : p^* = 32 mm

$d^* = \max[(d_t - 2e_t\, E_t/E\, f_t/f\, \rho),(d_t - 2e_t)]$= 25 mm

unperforated area : S = 0 mm²

center-to-center distance between rows : U_L = 0 mm

effective elastic constants	E^* = 30,226.4 MPa ν^* = 0.433	(Fig. 13.7.8-1 , Fig. 13.7.8.-2)
Bending stiffness	$D^* = (E^*.e^3)/(12(1-\nu^{*2}))$ = 1.176145×10⁹ N.mm	

[13.8] Maximum allowable stress for tube-to-tubesheet joint

Welded tube-to-tubesheet joint : $f_{t,j} = \min[(f_{min}.a_t/e_t),f_t]$ (a_t = 2.6 mm) ($f_{min} = \min[f, f_t]$) f_{tj} = 111.3 MPa

[13.9] Maximum permissible buckling stress limit for tubes

$$f_{t,bk} = \frac{1}{x}\left[\sigma_{t,p} + \frac{R_p^t - |x \cdot \sigma_{t,p}|}{\sqrt{1 + \left(\left((1+b_0)R_p^t - |x.\sigma_{t,p}|\right)/\sigma_{t,cr}\right)^2}}\right]$$

$f_{t,bk}$ shall be > 0

$$b_0 = 0{,}206\sqrt{\sigma_{t,cr}/R_p^t}\left(1 - 0{,}2\sqrt{\sigma_{t,cr}/R_p^t}\right)$$

$$\sigma_{t,p} = P_s d_t^2 - P_t (d_t - 2e_t)^2 / d_t^2 - (d_t - 2e_t)^2$$

$$\sigma_{t,cr} = \pi^2 E_t / l_{t,bk}^2 \cdot \left(d_t^2 + (d_t - 2e_t)^2\right)/16 = 120.43 \text{ MPa}$$

R_p^t = 167 MPa

x = 1.1

$l_{t,bk}$ = 1,000 mm

Parameters : F_q = 4.92	$F_{q,\infty}$ = 2.71	H = 5.33	H_∞ = 3.27	F_i = -0.477

[13.5.2] Conditions of applicability

$e_a \geq 0.75\, d_t$	$e_{a,p} \geq 0{,}8 e_a$	$U_L \leq 4p$
$L \geq 2 \times 1.4\sqrt{(D_s + e_s)e_s}$	$D_0 \geq 0{,}85 D_e$	$0{,}9D_s \leq G_c \leq 1{,}2D_s$

The shell shall be cylindrical, uniform thickness e_s and similar material.

The distance between the expansion joint and the tubsheet shall be ≥ l_s ($l_s = 1.4\sqrt{(D_s + e_s)e_s}$ =183.33 mm).

[13.5.3] – Parameters

L = 4,726.2 mm	l_1 = 0 mm	l_1' = 0 mm
$D_e = (D_s + G_c)/2$ = 1,319 mm	k_c = 0 N	
$h'_g = \max[(h_g - c_t),(0)]$ = 0 mm	$k_s = 2E_{s,1}\, e_{s,1}^{2,5} / [12(1-\nu_s^2)]^{0,75} / (D_s + e_{s,1})^{0,5}$ = 1,054,855 N	
$K_t = \pi e_t (d_t - e_t) E_t / L$ = 7,431.39 N/mm	$x_s = 1 - N_t (d_t/D_e)^2$ = 0.526	$X = (K_w/D^*)^{0,25}.D_e/2$ = 6.932
$K_w = 8N_t.K_t/\pi/D_e^2$ = 14.36 N/mm³	$x_t = 1 - N_t((d_t - 2e_t)/D_e)^2$ = 0.703	$Z = (k_s + k_c)/K_w^{0,25}/D^{*0,75}$ = 0.085
$K_s = \pi(D_s + e_s)/[(L - l_1 - l_1')/(e_s E_s) + (l_1 + l_1')/(e_{s,1} E_{s,1})]$=2,152,384 N/mm	K_J=/	w_J = /
$K_{s,t} = K_s/(N_t.K_t)$= 0.219	$J = 1/(1 + K_s/K_J)$ = 1	D_J = /
$\alpha_{s,m}(t_{s,m} - t_a)$=0.002268 mm/mm	$\alpha_{s,m,1}(t_{s,m} - t_a)$=0.002268 mm/mm	$\alpha_{t,m}(t_{t,m} - t_a)$=0.001717 mm/mm

$\gamma = [\alpha_{t,m}(t_{t,m} - t_a)\; L] - [\alpha_{s,m}(t_{s,m} - t_a)(L - l_1 - l_1') + \alpha_{s,m,1}(t_{s,m} - t_a)(l_1 + l_1')]$

[13.5.4.4] Effective pressure

$$P_e = \frac{J \cdot K_{s,t}}{1 + J \cdot K_{s,t} \cdot F_q}\left[\left[x_s + 2\nu_t(1 - x_s) + \frac{2\nu_s}{K_{s,t}} - \frac{1-J}{2J \cdot K_{s,t}}\frac{(D_J + 2w_j)^2 - D_S^2}{D_S^2}\right]P_S - \left[x_t + 2\nu_t(1 - x_t) + \frac{1}{J \cdot K_{s,t}}\right]P_t + \left[\frac{K_W}{2}\right]\gamma\right]$$

case	P_s (MPa)	P_t (MPa)	γ (mm)	P_e (MPa)
1	0.000	0.280	0.000	-0.161
2	0.100	0.000	0.000	0.037
3	0.100	0.280	0.000	-0.123
4	0.000	0.000	-2.604	-1.972
5	0.000	0.280	-2.604	-2.133
6	0.100	0.000	-2.604	-1.935
7	0.100	0.280	-2.604	-2.095

[13.5.5] Tubesheet calculation

Bending stress : $\sigma = 1/(4\mu^* H).[D_e/(e - h'_g)]^2.P_e$ (with $e = e_a$) $|\sigma|$ shall be ≤ σ_a

Shear stress : $\tau = 1/(2\mu).D_0/(2e).P_e$ (with $e = e_{ap}$) $|\tau|$ shall be ≤ τ_a

case	σ (MPa)	σ_a (MPa)	τ (MPa)	τ_a (MPa)
1	-11.432	1.5 f = 166.999	-3.470	0.8 f = 89.066
2	2.661	1.5 f = 166.999	0.808	0.8 f = 89.066
3	-8.771	1.5 f = 166.999	-2.662	0.8 f = 89.066
4	-140.367	2.25 f = 250.499	-42.605	0.8 f = 89.066
5	-151.799	2.25 f = 250.499	-46.075	0.8 f = 89.066
6	-137.706	2.25 f = 250.499	-41.798	0.8 f = 89.066
7	-149.138	2.25 f = 250.499	-45.268	0.8 f = 89.066

[13.5.6] Tubes calculation

Membrane stress :

Outer $\sigma_{t,0} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_q]$ $|\sigma_{t,0}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,0} < 0$ (tubes in compression) : $|\sigma_{t,0}|$ shall be ≤ $f_{t,bk}$

Inner $\sigma_{t,i} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_i]$ $|\sigma_{t,i}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,i} < 0$ (tubes in compression) : $|\sigma_{t,i}|$ shall be ≤ $f_{t,bk}$

Circumferential mean stress : $\sigma_{t,\theta} = [P_t(d_t - 2e_t) - P_s.d_t]/(2e_t)$

Radial mean stress : $\sigma_{t,r} = -(P_t + P_s)/2$

Total stress : $\sigma_{t,eq} = \max(|\sigma_{t,i} - \sigma_{t,\theta}|, |\sigma_{t,i} - \sigma_{t,r}|, |\sigma_{t,\theta} - \sigma_{t,r}|, |\sigma_{t,0} - \sigma_{t,\theta}|, |\sigma_{t,0} - \sigma_{t,r}|)$ $\sigma_{t,eq}$ shall be ≤ $\sigma_{t,a}$

case	$\sigma_{t,p}$ (MPa)	$\sigma_{t,0}$ (MPa)	$\sigma_{t,i}$ (MPa)	$f_{t,bk}$ (MPa)	$\sigma_{t,\theta}$ (MPa)	$\sigma_{t,r}$ (MPa)	$\sigma_{t,eq}$ (MPa)	$\sigma_{t,a}$ (MPa)
1	-0.471	3.361	-1.547	80.330	1.066	-0.140	3.501	f_t = 111.333
2	0.268	-0.744	0.398	81.110	-0.481	-0.050	0.879	f_t = 111.333
3	-0.203	2.617	-1.148	80.652	0.585	-0.190	2.807	f_t = 111.333
4	0.000	54.935	-5.325	80.896	0.000	0.000	54.935	1.5 f_t = 166.999
5	-0.471	58.297	-6.872	80.330	1.066	-0.140	58.437	1.5 f_t = 166.999
6	0.268	54.191	-4.927	81.110	-0.481	-0.050	54.672	1.5 f_t = 166.999
7	-0.203	57.552	-6.473	80.652	0.585	-0.190	57.742	1.5 f_t = 166.999

[13.5.7.1] Shell calculation (far from tubesheet)

Membrane stress :

$\sigma_{s,m} = D_s^2/(4e_s(D_s+e_s)).(P_t+P_e)$

Maximum permissible buckling stress limit :

$f_{s,bk} = K.e_s.E_s/4/(D_s+e_s)$ = 465.3 MPa (K=1) If $\sigma_{s,m} < 0$: $|\sigma_{s,m}|$ shall be $\leq f_{s,bk}$

Circumferential mean stress : $\sigma_{s,\theta} = P_s.D_s/2/e_s$

Radial mean stress : $\sigma_{s,r} = -P_s/2$

Total stress : $\sigma_{s,eq} = \max(|\sigma_{s,m} - \sigma_{s,\theta}|,|\sigma_{s,m} - \sigma_{s,r}|,|\sigma_{s,\theta} - \sigma_{s,r}|)$ $\sigma_{s,eq}$ shall be $\leq \sigma_{s,a}$

case	$\sigma_{s,m}$ (MPa)	$\sigma_{s,\theta}$ (MPa)	$\sigma_{s,r}$ (MPa)	$\sigma_{s,eq}$ (MPa)	$\sigma_{s,a}$ (MPa)
1	2.969	0.000	0.000	2.969	f_s = 134.667
2	0.930	5.023	-0.050	5.073	f_s = 134.667
3	3.899	5.023	-0.050	5.073	f_s = 134.667
4	-49.037	0.000	0.000	49.037	1.5 f_s = 202.001
5	-46.068	0.000	0.000	46.068	1.5 f_s = 202.001
6	-48.107	5.023	-0.050	53.130	1.5 f_s = 202.001
7	-45.138	5.023	-0.050	50.161	1.5 f_s = 202.001

[13.5.7.2] Shell calculation (tubesheet junction)

Membrane stress :

$\sigma_{s,m,1} = D_s^2/(4e_{s,1}(D_s+e_{s,1})).(P_t+P_e)$

Bending stress :

$\sigma_{s,b,1} = k_s/(k_s+k_c)(1/I_1)(D_e/2/e_{s,1})^2P_e$ (with : $I_1 = H_\infty[(2F_{q,\infty}/X/Z)+(1-(1-\nu^*)/X/Z)]$= 30.125)

Total stress (only normal operating conditions) :

$\sigma_{s,eq,1} = \max(|\sigma_{s,m,1} - \sigma_{s,b,1} + P_s|,|\sigma_{s,m,1} + \sigma_{s,b,1}|)$ $\sigma_{s,eq,1}$ shall be $\leq \sigma_{s,a,1}$

case	$\sigma_{s,m,1}$ (MPa)	$\sigma_{s,b,1}$ (MPa)	$\sigma_{s,eq,1}$ (MPa)	$\sigma_{s,a,1}$ (MPa)
1	2.969	-13.720	16.690	3 $f_{s,1}$ = 404.001
2	0.930	3.194	4.124	3 $f_{s,1}$ = 404.001
3	3.899	-10.527	14.525	3 $f_{s,1}$ = 404.001
4	-49.037	-168.461	217.498	3 $f_{s,1}$ = 404.001
5	-46.068	-182.182	228.250	3 $f_{s,1}$ = 404.001
6	-48.107	-165.267	213.375	3 $f_{s,1}$ = 404.001
7	-45.138	-178.988	224.126	3 $f_{s,1}$ = 404.001

[13.10] Tubesheet flanged extension :

$e_{fl,a}$ = 65.4 mm	P = 0.28 MPa	f = 111.3 MPa	f_A = 203.3 MPa
A = 1,502 mm	C = 1,430 mm	D_{ex} = 1,332 mm	G = 1,332 mm
$W = 0.1463\times10^7$ N	ν = 0.3	b = 0 mm	m = 1.2
$H = \pi/4\ G^2\ P$	$H_D = \pi/4\ D_{ex}^2\ P$	$H_T = H - H_D$	H_G = 0.0000 N
$h_D = (C - D_{ex})/2$	$h_G = (C - G)/2$	$h_T = (2C - D_{ex} - G)/4$	
$M_{op} = H_D.h_D + H_T.h_T + H_G.h_G = 19.11844\times10^6$ N.mm		$M_A = W.h_G = 71.66483\times10^6$ N.mm	

Maximum radial stress : $\sigma_r = 12M/\left(\pi A\left[(1+\nu)+(1-\nu)(D_{ex}/A)^2\right]e_{fl,a}^2\right)$ $D_{ex} \leq G$

Gasket seating : σ_r = 23.03 MPa ($M = M_A$) σ_r shall be $\leq f_A$

Operating condition : σ_r = 6.14 MPa ($M = M_{op}$) σ_r shall be $\leq f$

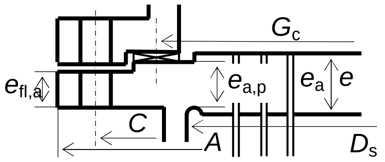
Error(s) and/or Warning(s)

The thickness is acceptable

Tubesheet, Loading conditions SS [test condition] (Without expansion joint).

EN 13445:2002 V26 (2007-04) §[13.5]	Tubesheet		Tubes	Shell		Channel
	Tubeside	Shellside		far tubesheet	near tubesheet	
Pressure (MPa)	P_t=0	P_s=2.135				
Corrosion	c_t=3 mm	c_s=3 mm		3 mm	3 mm	3 mm
Material	P355NH		P355NL1	P355NL1	P355NL1	P355NL1
Temperature	20 °C		20 °C	20 °C		20 °C
Mean Metal Temp.			$t_{t,m}$=20 °C	$t_{s,m}$=20 °C		
Allowable stress	f = 290.5 MPa		f_t = 338.1 MPa	f_s = 328.6 MPa	$f_{s,1}$ = 328.6 MPa	f_c = 328.6 MPa
Modulus of elasticity	E = 201,000 MPa		E_t=201,000 MPa	E_s=201,000 MPa	$E_{s,1}$=201,000 MPa	E_c=201,000 MPa
Uncorroded thick.	**80 mm**		e_t=2.6 mm	16 mm	16 mm	16 mm
Diameter	A = 1,502 mm		d_t=25 mm	1,300 mm	1,300 mm	1,300 mm
Tolerance	1.6 mm					
Poisson's ratio	ν = 0.3		ν_t = 0.3	ν_s = 0.3		ν_c = 0.3

Pattern : Triangular	N_t=1320	OTL=1,274.23 m m	p=32 mm



Configuration b	e_s = 13 mm	e_c = 13 mm
D_s = 1,306 mm	C = 1,430 mm	e_a = 72.4 mm
D_c = 1,306 mm	G_c = 1,332 mm	$e_{a,p}$ = 67.4 mm
h_g = 0 mm	Flange face = 8 mm	$e_{fl,a}$ = 0 mm
Extra thickness (periphery):	Tubeside = 5 mm	Shellside = 0 mm

[13.7] Tubesheet properties	$e = e_a$	
Diameter of perforated region	$D_0 = 2r_0+d_t$	r_0 = 624.615 mm
Tube expansion depth ratio	$\rho = l_{t,x}/e$ = 0	$l_{t,x}$ = 0 mm

Ligament efficiency : basic : $\mu = (p- d_t)/p$ = 0.219 — effective : $\mu^* = (p^* - d^*)/ p^*$ = 0.219

$$p^* = \frac{p}{\sqrt{1-4\frac{\min[(S),(4D_0 \cdot p)]}{\pi \cdot D_0^2}}}$$

or if one unperforated lane and $U_L \leq 4p$:

$$p^* = \frac{p}{\sqrt{1-\frac{4 \cdot U_L}{\pi \cdot D_0}}}$$

effective tube pitch : p^* = 32 mm

$d^* = \max[(d_t -2e_t\, E_t/E\, f_t/f\, \rho),(d_t -2e_t)]$= 25 mm

unperforated area : S = 0 mm²

center-to-center distance between rows : U_L = 0 mm

effective elastic constants	E^* = 35,738.2 MPa ν^* = 0.433	(Fig. 13.7.8-1 , Fig. 13.7.8.-2)
Bending stiffness	$D^* = (E^*.e^3)/(12(1-\nu^{*2}))$ = 1.390618×10^9 N.mm	

[13.8] Maximum allowable stress for tube-to-tubesheet joint

Welded tube-to-tubesheet joint : $f_{t,j} = \min[(f_{\min} .a_t /e_t),f_t]$ (a_t = 2.6 mm) ($f_{\min} = \min[f , f_t]$) f_{tj} = 290.5 MPa

[13.9] Maximum permissible buckling stress limit for tubes

$$f_{t,bk} = \frac{1}{x}\left[\sigma_{t,p} + \frac{R_p^t - |x \cdot \sigma_{t,p}|}{\sqrt{1+\left(\left((1+b_0)R_p^t - |x.\sigma_{t,p}|\right)/\sigma_{t,cr}\right)^2}}\right]$$

$f_{t,bk}$ shall be > 0

$$b_0 = 0{,}206\sqrt{\sigma_{t,cr}/R_p^t}\left(1-0{,}2\sqrt{\sigma_{t,cr}/R_p^t}\right)$$

$$\sigma_{t,p} = P_s d_t^2 - P_t (d_t - 2e_t)^2 / d_t^2 - (d_t - 2e_t)^2$$

$$\sigma_{t,cr} = \pi^2 E_t / l_{t,bk}^2 \cdot \left(d_t^2 + (d_t - 2e_t)^2\right)/16 = 126.1 \text{ MPa}$$

R_p^t = 355 MPa

x = 1.1

$l_{t,bk}$ = 1,000 mm

Parameters :	F_q = 4.78	$F_{q,\infty}$ = 2.63	H = 5.09	H_∞ = 3.16	F_i = -0.479

[13.5.2] Conditions of applicability

$e_a \geq 0.75\, d_t$ $e_{a,p} \geq 0{,}8 e_a$ $U_L \leq 4p$

$L \geq 2\times 1.4\sqrt{(D_s + e_s)e_s}$ $D_0 \geq 0{,}85 D_e$

The shell shall be cylindrical, uniform thickness e_s and similar material.

The distance between the expansion joint and the tubsheet shall be ≥ l_s ($l_s = 1.4\sqrt{(D_s + e_s)e_s}$ =183.33 mm).

[13.5.3] – Parameters

L = 4,726.2 mm	l_1 = 0 mm	l_1' = 0 mm
$D_e = D_s$ = 1,306 mm	k_c = 0 N	
$h'_g = \max[(h_g - c_t),(0)]$ = 0 mm	$k_s = 2E_{s,1}\, e_{s,1}^{2,5} / [12(1-\nu_s^2)]^{0,75} / (D_s + e_{s,1})^{0,5}$ = 1,122,781 N	
$K_t = \pi e_t (d_t - e_t) E_t / L$ = 7,781.35 N/mm	$x_s = 1 - N_t (d_t / D_e)^2$ = 0.516	$X = (K_w / D^*)^{0,25} . D_e / 2$ = 6.692
$K_w = 8 N_t . K_t / \pi / D_e^2$ = 15.33 N/mm³	$x_t = 1 - N_t ((d_t - 2e_t)/D_e)^2$ = 0.697	$Z = (k_s + k_c)/K_w^{0,25} / D^{*0,75}$ = 0.079
$K_s = \pi (D_s + e_s) / [(L - l_1 - l_1')/(e_s E_s) + (l_1 + l_1')/(e_{s,1} E_{s,1})]$ = 2,290,983 N/mm	K_J =/	w_J = /
$K_{s,t} = K_s / (N_t . K_t)$ = 0.223	$J = 1/(1 + K_s / K_J)$ = 1	D_J = /
$\alpha_{s,m}(t_{s,m} - t_a)$=0 mm/mm	$\alpha_{s,m,1}(t_{s,m} - t_a)$=0 mm/mm	$\alpha_{t,m}(t_{t,m} - t_a)$=0 mm/mm

$\gamma = [\alpha_{t,m} (t_{t,m} - t_a)\ L] - [\alpha_{s,m} (t_{s,m} - t_a) (L - l_1 - l_1') + \alpha_{s,m,1} (t_{s,m} - t_a) (l_1 + l_1')]$

[13.5.4.4] Effective pressure

$$P_e = \frac{J \cdot K_{s,t}}{1 + J \cdot K_{s,t} \cdot F_q} \left[\left[x_s + 2\nu_t (1 - x_s) + \frac{2\nu_s}{K_{s,t}} - \frac{1-J}{2J \cdot K_{s,t}} \frac{(D_J + 2w_j)^2 - D_S^2}{D_S^2} \right] P_S - \left[x_t + 2\nu_t (1 - x_t) + \frac{1}{J \cdot K_{s,t}} \right] P_t + \left[\frac{K_W}{2} \right] \gamma \right]$$

case	P_s (MPa)	P_t (MPa)	γ (mm)	P_e (MPa)
1	0.000	0.000	0.000	0.000
2	2.135	0.000	0.000	0.806
3	2.135	0.000	0.000	0.806

[13.5.5] Tubesheet calculation

Bending stress : $\sigma = 1/(4\mu^* H).[D_e/(e - h'_g)]^2.P_e$ (with $e = e_a$) $|\sigma|$ shall be ≤ σ_a

Shear stress : $\tau = 1/(2\mu).D_0/(2e).P_e$ (with $e = e_{ap}$) $|\tau|$ shall be ≤ τ_a

case	σ (MPa)	σ_a (MPa)	τ (MPa)	τ_a (MPa)
1	0.000	1.5 f = 435.714	0.000	0.8 f = 232.381
2	58.851	1.5 f = 435.714	17.408	0.8 f = 232.381
3	58.851	1.5 f = 435.714	17.408	0.8 f = 232.381

[13.5.6] Tubes calculation

Membrane stress :

Outer $\sigma_{t,0} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_q]$ $|\sigma_{t,0}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,0} < 0$ (tubes in compression) : $|\sigma_{t,0}|$ shall be ≤ $f_{t,bk}$

Inner $\sigma_{t,i} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_i]$ $|\sigma_{t,i}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,i} < 0$ (tubes in compression) : $|\sigma_{t,i}|$ shall be ≤ $f_{t,bk}$

Circumferential mean stress : $\sigma_{t,\theta} = [P_t(d_t - 2e_t) - P_s.d_t]/(2e_t)$

Radial mean stress : $\sigma_{t,r} = -(P_t + P_s)/2$

Total stress : $\sigma_{t,eq} = \max(|\sigma_{t,i} - \sigma_{t,\theta}|,|\sigma_{t,i} - \sigma_{t,r}|,|\sigma_{t,\theta} - \sigma_{t,r}|,|\sigma_{t,0} - \sigma_{t,\theta}|,|\sigma_{t,0} - \sigma_{t,r}|)$ $\sigma_{t,eq}$ shall be ≤ $\sigma_{t,a}$

case	$\sigma_{t,p}$ (MPa)	$\sigma_{t,0}$ (MPa)	$\sigma_{t,i}$ (MPa)	$f_{t,bk}$ (MPa)	$\sigma_{t,\theta}$ (MPa)	$\sigma_{t,r}$ (MPa)	$\sigma_{t,eq}$ (MPa)	$\sigma_{t,a}$ (MPa)
1	0.000	0.000	0.000	98.512	0.000	0.000	0.000	f_t = 338.095
2	5.728	-15.256	8.256	103.916	-10.264	-1.067	18.521	f_t = 338.095
3	5.728	-15.256	8.256	103.916	-10.264	-1.067	18.521	f_t = 338.095

[13.5.7.1] Shell calculation (far from tubesheet)

Membrane stress :

$\sigma_{s,m} = D_s^2/(4e_s(D_s + e_s)).(P_t + P_e)$

Maximum permissible buckling stress limit :

$f_{s,bk} = K.e_s.E_s/4/(D_s + e_s)$ = 668.6 MPa (K=1.35) If $\sigma_{s,m} < 0$: $|\sigma_{s,m}|$ shall be ≤ $f_{s,bk}$

Circumferential mean stress : $\sigma_{s,\theta} = P_s.D_s/2/e_s$

Radial mean stress : $\sigma_{s,r} = -P_s/2$

Total stress : $\sigma_{s,eq} = \max(|\sigma_{s,m} - \sigma_{s,\theta}|,|\sigma_{s,m} - \sigma_{s,r}|,|\sigma_{s,\theta} - \sigma_{s,r}|)$ $\sigma_{s,eq}$ shall be ≤ $\sigma_{s,a}$

case	$\sigma_{s,m}$ (MPa)	$\sigma_{s,\theta}$ (MPa)	$\sigma_{s,r}$ (MPa)	$\sigma_{s,eq}$ (MPa)	$\sigma_{s,a}$ (MPa)
1	0.000	0.000	0.000	0.000	f_s = 328.571
2	20.036	107.243	-1.067	108.310	f_s = 328.571
3	20.036	107.243	-1.067	108.310	f_s = 328.571

[13.5.7.2] Shell calculation (tubesheet junction)

Membrane stress :

$\sigma_{s,m,1} = D_s^2/(4e_{s,1}(D_s+e_{s,1})).(P_t+P_e)$

Bending stress :

$\sigma_{s,b,1} = k_s/(k_s+k_c)(1/I_1)(D_e/2/e_{s,1})^2 P_e$ (with : $I_1 = H_\infty[(2F_{q,\infty}/X/Z)+(1-(1-\nu^*)/X/Z)]$= 31.221)

Total stress (only normal operating conditions) :

$\sigma_{s,eq,1}$= max($|\sigma_{s,m,1}-\sigma_{s,b,1}+P_s|,|\sigma_{s,m,1}+\sigma_{s,b,1}|$) $\sigma_{s,eq,1}$ shall be ≤ $\sigma_{s,a,1}$

case	$\sigma_{s,m,1}$ (MPa)	$\sigma_{s,b,1}$ (MPa)	$\sigma_{s,eq,1}$ (MPa)	$\sigma_{s,a,1}$ (MPa)
1	0.000	0.000	0.000	+∞
2	20.036	65.114	85.150	+∞
3	20.036	65.114	85.150	+∞

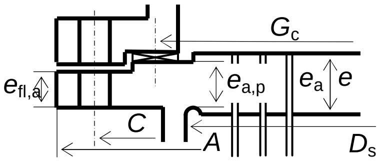
Error(s) and/or Warning(s)

The thickness is acceptable

Tubesheet, Loading conditions TS [test condition] (Without expansion joint).

EN 13445:2002 V26 (2007-04) §[13.5]	Tubesheet		Tubes	Shell		Channel
	Tubeside	Shellside		far tubesheet	near tubesheet	
Pressure (MPa)	P_t=0.859	P_s=0				
Corrosion	c_t=3 mm	c_s=3 mm		3 mm	3 mm	3 mm
Material	P355NH		P355NL1	P355NL1	P355NL1	P355NL1
Temperature	20 °C		20 °C	20 °C		20 °C
Mean Metal Temp.			$t_{t,m}$=20 °C	$t_{s,m}$=20 °C		
Allowable stress	f = 290.5 MPa		f_t = 338.1 MPa	f_s = 328.6 MPa	$f_{s,1}$ = 328.6 MPa	f_c = 328.6 MPa
Modulus of elasticity	E = 201,000 MPa		E_t=201,000 MPa	E_s=201,000 MPa	$E_{s,1}$=201,000 MPa	E_c=201,000 MPa
Uncorroded thick.	**80 mm**		e_t=2.6 mm	16 mm	16 mm	16 mm
Diameter	A = 1,502 mm		d_t=25 mm	1,300 mm	1,300 mm	1,300 mm
Tolerance	1.6 mm					
Poisson's ratio	ν = 0.3		ν_t = 0.3	ν_s = 0.3		ν_c = 0.3

Pattern : Triangular	N_t=1320	OTL=1,274.23 mm	p=32 mm



Configuration b	e_s = 13 mm	e_c = 13 mm
D_s = 1,306 mm	C = 1,430 mm	e_a = 72.4 mm
D_c = 1,306 mm	G_c = 1,332 mm	$e_{a,p}$ = 67.4 mm
h_g = 0 mm	Flange face = 8 mm	$e_{fl,a}$ = 65.4 mm
Extra thickness (periphery):	Tubeside = 5 mm	Shellside = 0 mm

[13.7] Tubesheet properties	$e = e_a$	
Diameter of perforated region	$D_0 = 2r_0+d_t$	r_0 = 624.615 mm
Tube expansion depth ratio	$\rho = l_{t,x}/e = 0$	$l_{t,x}$ = 0 mm

Ligament efficiency : basic : $\mu = (p- d_t)/p$ = 0.219 — effective : $\mu^* = (p^* - d^*)/ p^*$ = 0.219

$$p^* = \frac{p}{\sqrt{1-4\dfrac{\min[(S),(4D_0\cdot p)]}{\pi\cdot D_0^2}}}$$

or if one unperforated lane and $U_L \le 4p$:

$$p^* = \frac{p}{\sqrt{1-\dfrac{4\cdot U_L}{\pi\cdot D_0}}}$$

effective tube pitch : p^* = 32 mm

$d^* = \max[(d_t -2e_t\, E_t/E\, f_t/f\, \rho),(d_t -2e_t)]$= 25 mm

unperforated area : S = 0 mm²

center-to-center distance between rows : U_L = 0 mm

effective elastic constants	E^* = 35,738.2 MPa	ν^* = 0.433	(Fig. 13.7.8-1 , Fig. 13.7.8.-2)
Bending stiffness	$D^* = (E^*.e^3)/(12(1-\nu^{*2}))$ = 1.390618×10^9 N.mm		

[13.8] Maximum allowable stress for tube-to-tubesheet joint

Welded tube-to-tubesheet joint : $f_{t,j} = \min[(f_{min}\,.a_t/e_t),f_t]$ (a_t = 2.6 mm) ($f_{min} = \min[f, f_t]$) f_{tj} = 290.5 MPa

[13.9] Maximum permissible buckling stress limit for tubes

$$f_{t,bk} = \frac{1}{x}\left[\sigma_{t,p} + \frac{R_p^t - |x\cdot\sigma_{t,p}|}{\sqrt{1+\left(\left((1+b_0)R_p^t - |x.\sigma_{t,p}|\right)/\sigma_{t,cr}\right)^2}}\right]$$

$f_{t,bk}$ shall be > 0

$$b_0 = 0{,}206\sqrt{\sigma_{t,cr}/R_p^t}\left(1-0{,}2\sqrt{\sigma_{t,cr}/R_p^t}\right)$$

$$\sigma_{t,p} = P_s d_t^2 - P_t(d_t-2e_t)^2 / d_t^2 - (d_t-2e_t)^2$$

$$\sigma_{t,cr} = \pi^2 E_t / l_{t,bk}^2 \cdot \left(d_t^2 + (d_t-2e_t)^2\right)/16 = 126.1 \text{ MPa}$$

R^t_p = 355 MPa
x = 1.1
$l_{t,bk}$ = 1,000 mm

Parameters :	F_q = 4.80	$F_{q,\infty}$ = 2.64	H = 5.12	H_∞ = 3.17	F_i = -0.479

[13.5.2] Conditions of applicability

$e_a \ge 0.75\, d_t$	$e_{a,p} \ge 0{,}8e_a$	$U_L \le 4p$
$L \ge 2\times1.4\sqrt{(D_s+e_s)e_s}$	$D_0 \ge 0{,}85D_e$	$0{,}9D_s \le G_c \le 1{,}2D_s$

The shell shall be cylindrical, uniform thickness e_s and similar material.

The distance between the expansion joint and the tubsheet shall be ≥ l_s ($l_s = 1.4\sqrt{(D_s+e_s)e_s}$ =183.33 mm).

[13.5.3] – Parameters

L = 4,726.2 mm	l_1 = 0 mm	l_1' = 0 mm
$D_e = (D_s + G_c)/2$ = 1,319 mm	k_c = 0 N	
$h'_g = \max[(h_g - c_t),(0)]$ = 0 mm	$k_s = 2E_{s,1}\, e_{s,1}^{2,5} / [12(1-\nu_s^2)]^{0,75} / (D_s + e_{s,1})^{0,5}$ = 1,122,781 N	
$K_t = \pi e_t (d_t - e_t) E_t / L$ = 7,781.35 N/mm	$x_s = 1 - N_t (d_t / D_e)^2$ = 0.526	$X = (K_w / D^*)^{0,25} . D_e / 2$ = 6.725
$K_w = 8N_t . K_t / \pi / D_e^2$ = 15.03 N/mm³	$x_t = 1 - N_t ((d_t - 2e_t)/D_e)^2$ = 0.703	$Z = (k_s + k_c)/K_w^{0,25} / D^{*0,75}$ = 0.079
$K_s = \pi (D_s + e_s) / [(L - l_1 - l_1')/(e_s E_s) + (l_1 + l_1')/(e_{s,1} E_{s,1})]$ = 2,290,983 N/mm	K_J = /	w_J = /
$K_{s,t} = K_s / (N_t . K_t)$ = 0.223	$J = 1/(1 + K_s / K_J)$ = 1	D_J = /
$\alpha_{s,m}(t_{s,m} - t_a)$ = 0 mm/mm	$\alpha_{s,m,1}(t_{s,m} - t_a)$ = 0 mm/mm	$\alpha_{t,m}(t_{t,m} - t_a)$ = 0 mm/mm
$\gamma = [\alpha_{t,m}(t_{t,m} - t_a)\, L] - [\alpha_{s,m}(t_{s,m} - t_a)(L - l_1 - l_1') + \alpha_{s,m,1}(t_{s,m} - t_a)(l_1 + l_1')]$		

[13.5.4.4] Effective pressure

$$P_e = \frac{J \cdot K_{s,t}}{1 + J \cdot K_{s,t} \cdot F_q}\left[\left[x_s + 2\nu_t(1 - x_s) + \frac{2\nu_s}{K_{s,t}} - \frac{1-J}{2J \cdot K_{s,t}}\frac{(D_J + 2w_j)^2 - D_S^2}{D_S^2}\right]P_S - \left[x_t + 2\nu_t(1 - x_t) + \frac{1}{J \cdot K_{s,t}}\right]P_t + \left[\frac{K_W}{2}\right]\gamma\right]$$

case	P_s (MPa)	P_t (MPa)	γ (mm)	P_e (MPa)
1	0.000	0.859	0.000	-0.496
2	0.000	0.000	0.000	0.000
3	0.000	0.859	0.000	-0.496

[13.5.5] Tubesheet calculation

Bending stress : $\sigma = 1/(4\mu^* H).[D_e/(e - h'_g)]^2.P_e$ (with $e = e_a$) $|\sigma|$ shall be ≤ σ_a

Shear stress : $\tau = 1/(2\mu).D_0/(2e).P_e$ (with $e = e_{ap}$) $|\tau|$ shall be ≤ τ_a

case	σ (MPa)	σ_a (MPa)	τ (MPa)	τ_a (MPa)
1	-36.758	1.5 f = 435.714	-10.721	0.8 f = 232.381
2	0.000	1.5 f = 435.714	0.000	0.8 f = 232.381
3	-36.758	1.5 f = 435.714	-10.721	0.8 f = 232.381

[13.5.6] Tubes calculation

Membrane stress :

Outer $\sigma_{t,0} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_q]$ $|\sigma_{t,0}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,0} < 0$ (tubes in compression) : $|\sigma_{t,0}|$ shall be ≤ $f_{t,bk}$

Inner $\sigma_{t,i} = 1/(x_t - x_s)[(P_s.x_s - P_t.x_t) - P_e.F_i]$ $|\sigma_{t,i}|$ shall be ≤ $f_{t,j}$

If $\sigma_{t,i} < 0$ (tubes in compression) : $|\sigma_{t,i}|$ shall be ≤ $f_{t,bk}$

Circumferential mean stress : $\sigma_{t,\theta} = [P_t(d_t - 2e_t) - P_s.d_t]/(2e_t)$

Radial mean stress : $\sigma_{t,r} = -(P_t + P_s)/2$

Total stress : $\sigma_{t,eq} = \max(|\sigma_{t,i} - \sigma_{t,\theta}|, |\sigma_{t,i} - \sigma_{t,r}|, |\sigma_{t,\theta} - \sigma_{t,r}|, |\sigma_{t,0} - \sigma_{t,\theta}|, |\sigma_{t,0} - \sigma_{t,r}|)$ $\sigma_{t,eq}$ shall be ≤ $\sigma_{t,a}$

case	$\sigma_{t,p}$ (MPa)	$\sigma_{t,0}$ (MPa)	$\sigma_{t,i}$ (MPa)	$f_{t,bk}$ (MPa)	$\sigma_{t,\theta}$ (MPa)	$\sigma_{t,r}$ (MPa)	$\sigma_{t,eq}$ (MPa)	$\sigma_{t,a}$ (MPa)
1	-1.446	10.070	-4.760	96.986	3.271	-0.430	10.499	f_t = 338.095
2	0.000	0.000	0.000	98.512	0.000	0.000	0.000	f_t = 338.095
3	-1.446	10.070	-4.760	96.986	3.271	-0.430	10.499	f_t = 338.095

[13.5.7.1] Shell calculation (far from tubesheet)

Membrane stress :

$\sigma_{s,m} = D_s^2/(4e_s(D_s + e_s)).(P_t + P_e)$

Maximum permissible buckling stress limit :

$f_{s,bk} = K.e_s.E_s/4/(D_s + e_s)$ = 668.6 MPa (K=1.35) If $\sigma_{s,m} < 0$: $|\sigma_{s,m}|$ shall be ≤ $f_{s,bk}$

Circumferential mean stress : $\sigma_{s,\theta} = P_s.D_s/2/e_s$

Radial mean stress : $\sigma_{s,r} = -P_s/2$

Total stress : $\sigma_{s,eq} = \max(|\sigma_{s,m} - \sigma_{s,\theta}|, |\sigma_{s,m} - \sigma_{s,r}|, |\sigma_{s,\theta} - \sigma_{s,r}|)$ $\sigma_{s,eq}$ shall be ≤ $\sigma_{s,a}$

case	$\sigma_{s,m}$ (MPa)	$\sigma_{s,\theta}$ (MPa)	$\sigma_{s,r}$ (MPa)	$\sigma_{s,eq}$ (MPa)	$\sigma_{s,a}$ (MPa)
1	9.022	0.000	0.000	9.022	f_s = 328.571
2	0.000	0.000	0.000	0.000	f_s = 328.571
3	9.022	0.000	0.000	9.022	f_s = 328.571

[13.5.7.2] Shell calculation (tubesheet junction)

Membrane stress :

$\sigma_{s,m,1} = D_s^2/(4e_{s,1}(D_s+e_{s,1})).(P_t+P_e)$

Bending stress :

$\sigma_{s,b,1} = k_s/(k_s+k_c)(1/I_1)(D_e/2/e_{s,1})^2P_e$ (with : $I_1 = H_\infty[(2F_{q,\infty}/X/Z)+(1-(1-\nu^*)/X/Z)]$= 31.237)

Total stress (only normal operating conditions) :

$\sigma_{s,eq,1}$= max($|\sigma_{s,m,1}-\sigma_{s,b,1}+P_s|,|\sigma_{s,m,1}+\sigma_{s,b,1}|$) $\sigma_{s,eq,1}$ shall be ≤ $\sigma_{s,a,1}$

case	$\sigma_{s,m,1}$ (MPa)	$\sigma_{s,b,1}$ (MPa)	$\sigma_{s,eq,1}$ (MPa)	$\sigma_{s,a,1}$ (MPa)
1	9.022	-40.881	49.903	+∞
2	0.000	0.000	0.000	+∞
3	9.022	-40.881	49.903	+∞

[13.10] Tubesheet flanged extension :

$e_{fl,a}$ = 65.4 mm	P = 0.859 MPa	f = 290.5 MPa	f_A = 203.3 MPa
A = 1,502 mm	C = 1,430 mm	D_{ex} = 1,332 mm	G = 1,332 mm
$W = 0.1463\times10^7$ N	ν = 0.3	b = 0 mm	m = 1.2
$H = \pi/4\ G^2\ P$	$H_D = \pi/4\ D_{ex}^2\ P$	$H_T = H - H_D$	H_G = 0.0000 N
$h_D = (C - D_{ex})/2$	$h_G = (C - G)/2$	$h_T = (2C - D_{ex} - G)/4$	

$M_{op} = H_D.h_D + H_T.h_T + H_G.h_G = 58.65264\times10^6$ N.mm $M_A = W.h_G = 71.66483\times10^6$ N.mm

Maximum radial stress : $\sigma_r = 12M/\left(\pi A\left[(1+\nu)+(1-\nu)(D_{ex}/A)^2\right]e_{fl,a}^2\right)$ $D_{ex} \le G$

Gasket seating : σ_r = 23.03 MPa ($M = M_A$) σ_r shall be ≤ f_A

Operating condition : σ_r = 18.85 MPa ($M = M_{op}$) σ_r shall be ≤ f

Error(s) and/or Warning(s)

The thickness is acceptable

Tubes.

Tube of bundle in internal pressure.

Material : P355NL1 EN 10216-3	Seamless pipe	
Temperature : T = 400 °C	Joint efficiency : v = 1	Carbon Steel
Nominal thickness : s_e = 2.60 mm	Outside diameter : D_a = 25.00 mm	
p = internal pressure	K/S = allowable stress	c = corrosion allowance
e = minimal required thickness	σ = circular stress	p_{max} = max. allowable pressure

	p (MPa)	K/S (MPa)	e+c (mm)	σ (MPa)	c (mm)	p_{max} (MPa)
Horizontal test	0.859	338.1	2.03	15.94	2.00	18.2254
Operation	0.683	111.33	2.07	12.67	2.00	6.0015

Tube of bundle in external pressure.

Material : P355NL1 EN 10216-3	Seamless pipe	
p = external pressure	t = temperature	Carbon Steel
K/S= alllowable stress	E = modulus of elasticity	ν = 0.3
Actual thickness : s_e = 0.60 mm	Outside diameter : D_a = 25.00 mm	c_1+c_2 = corrosion + tolerance

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l = 4,717.00 mm
u = 1.5%

$$p_1 = \frac{E}{S_k} \frac{2}{1-\nu^2} \left(\frac{s_e - c_1 - c_2}{D_a} \right)^3$$

$$p_2 = 2 \frac{K}{S} \frac{s_e - c_1 - c_2}{D_a} \frac{1}{1 + \frac{1.5u(1-0.2 D_a/l) D_a}{100(s_e - c_1 - c_2)}}$$

p (MPa)	t (°C)	K/S (MPa)	E (MPa)	S_k	c_1+c_2 (mm)	min(p_1 ; p_2) (MPa)
2.135	20	338.1	201,000	3	2.00	2.6463
1.103	400	111.33	170,000	3	2.00	2.2382

Maximum Allowable Working Pressure

Maximum Allowable Working Pressure(Geometry).

Type / Mark		Diameter	Thickness	Internal		External		Hydrostatic	
				Operation	Test	Operation	Test	Operation	Test
		(mm)	(mm)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)
01 KH	TS01	1,300.0	20.0	4.8458	8.1993	5.6104	/	0.0000	0.0127
02 SH	TS02	1,300.0	16.0	3.8220	6.4768	2.5597	/	0.0000	0.0127
03 EF	GF01			0.9624	2.8486	/	/	0.0000	0.0127
05 TT	TT01			0.6051	11.6106	3.8597	/	/	/
05 TT	TT01			2.6545	6.4768	3.5240	/	/	/
06 SH	SS01	1,300.0	16.0	2.6545	6.4768	0.4363	/	0.0000	0.0127
07 SH	SS01	1,300.0	16.0	2.6545	6.4768	0.4363	/	0.0000	0.0127
08 TT	TT02			2.6545	6.4768	3.5240	/	/	/
08 TT	TT02			0.6051	11.6106	3.8597	/	/	/
10 EF	GF02			0.9624	2.8486	/	/	0.0000	0.0127
11 SH	TS03	1,300.0	16.0	3.8220	6.4768	1.2097	/	0.0000	0.0127
12 KH	TS04	1,300.0	16.0	3.8220	6.4768	3.2804	/	0.0000	0.0127

Type : SH = Shell ; CT = Cone ; SK = Skirt ; TT = Tubesheet ; AF, BL, BF, CF, EF, DF ,WN, SO, EM, CL = Flange ;
EH, GH, KH, FH, HH,TH = Elliptical, GRC, Korboggen, Flat, Hemispherical, Torispherical Head.

Maximum Allowable Working Pressure (Nozzles).

Tag	Neck		Flange		Hydrostatic Pressure	
	Operation	Test	Operation	Test	Operation	Test
	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)
I1	6.6679	20.2490	/	/	0.0000	0.0127
O1	13.4418	32.7956	/	/	0.0000	0.0127
O2	6.3014	10.6786	/	/	0.0000	0.0127
I2	6.7124	12.4175	/	/	0.0000	0.0127
V1	39.1306	66.3107	/	/	0.0000	0.0127
T	57.3039	93.0952	/	/	0.0000	0.0127

Isolated Opening(s)
Opening reinforcement I1 int. pressure Shell Side Inlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
DESIGN PRESSURE P              1.0000 MPa
TEMPERATURE                    400.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 134.67 /     111.33 MPa
          PAD R                                                 134.67 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT             1332.00 /     273.00 mm
THICKNESS SHELL E / NOZZLE ET                       16.00 /      10.94 mm
NOZZLE SCHEDULE
FLANGE RATING                  300.   lb
NOZZLE HEIGHT  H               254.00 mm
NOZZLE INTERNAL HEIGHT M         0.00 mm
FLANGE HEIGHT EB               117.35 mm
REINFORCEMENT WIDTH LR         174.00 mm
REINFORCEMENT THICKNESS ER      16.00 mm
ECCENTRICITY                     0.00 mm
NOZZLE SLOPE ANGLE A             0.00 °

VESSEL in OPERATION           * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2*T+P).......................=      1.22 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ..................................=      0.00 mm
                 sA = E+h ..............................=     16.00 mm
                 sS = ET ...............................=     10.94 mm
                 di = (DT-2*(ET-CT)) ...................=    257.12 mm
                 Di = D-2*(E-C).........................=   1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    130.95 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=     57.34 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    130.95 mm
                 lSr=...................................=     57.34 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     1702. mm²
                 As1 = .................................=      558. mm²
                 As2 = .................................=     2095. mm²
                 Ap = ..................................=   183685. mm²
                 (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =   571376. N
                                                >= P*Ap =   183685. N

                 h1 = ..................................=     16.00 mm
                 b1 = ..................................=    174.00 mm
                 b1.h1 >= b.h
```

Opening reinforcement I1 int. pressure Shell Side Inlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
DESIGN PRESSURE P               2.1477 MPa
TEMPERATURE                      20.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 328.57 /     338.10 MPa
          PAD R                                                 328.57 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT             1332.00 /     273.00 mm
THICKNESS SHELL E / NOZZLE ET                       16.00 /      10.94 mm
NOZZLE SCHEDULE
FLANGE RATING                   300.   lb
NOZZLE HEIGHT  H                254.00 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                117.35 mm
REINFORCEMENT WIDTH LR          174.00 mm
REINFORCEMENT THICKNESS ER       16.00 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in TEST                 * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2*T+P).......................=      0.86 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ...................................=      0.00 mm
                 sA = E+h ...............................=     16.00 mm
                 sS = ET ................................=     10.94 mm
                 di = (DT-2*(ET-CT)) ....................=    257.12 mm
                 Di = D-2*(E-C)..........................=   1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    130.95 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=     57.34 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =....................................=    130.95 mm
                 lSr=....................................=     57.34 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = ..................................=     1702. mm²
                 As1 = ..................................=      558. mm²
                 As2 = ..................................=     2095. mm²
                 Ap = ...................................=   183685. mm²
                 P*[Ap/(As0+As1+As2)+1/2]                =     91.65 MPa
                                                  <= S =    328.57 MPa

                 h1 = ...................................=     16.00 mm
                 b1 = ...................................=    174.00 mm
                 b1.h1 >= b.h
```

Opening reinforcement I1 ext. pressure Shell Side Inlet

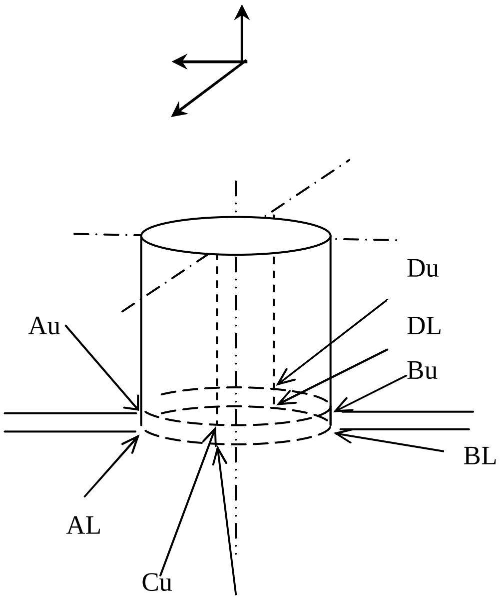
```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
EXT. PRESSURE                  0.1030 MPa
TEMPERATURE                    400.0  °C
CORROSION SHELL C /NOZZLE CT                        3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                178.78 /     167.71 MPa
          PAD R                                                178.78 MPa
JOINT EFFICIENCY V                                  1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT            1332.00 /     273.00 mm
THICKNESS SHELL E / NOZZLE ET                      16.00 /      10.94 mm
NOZZLE SCHEDULE
FLANGE RATING                  300.   lb
NOZZLE HEIGHT  H               254.00 mm
NOZZLE INTERNAL HEIGHT M         0.00 mm
FLANGE HEIGHT EB               117.35 mm
REINFORCEMENT WIDTH LR         174.00 mm
REINFORCEMENT THICKNESS ER      16.00 mm
ECCENTRICITY                     0.00 mm
NOZZLE SLOPE ANGLE A             0.00 °

VESSEL in EXTERNAL PRESSURE    * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =..................................=     0.86 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ..................................=     0.00 mm
                 sA = E+h ..............................=    16.00 mm
                 sS = ET ...............................=    10.94 mm
                 di = (DT-2*(ET-CT)) ...................=   257.12 mm
                 Di = D-2*(E-C).........................=  1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=   130.95 mm
                 psi = Nozzle deflection angle / shell   =    90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=    57.34 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=   130.95 mm
                 lSr=...................................=    57.34 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=    1702. mm²
                 As1 = .................................=     558. mm²
                 As2 = .................................=    2095. mm²
                 Ap = ..................................=  183685. mm²
                 (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =  772297. N
                                                >= P*Ap =   18920. N

                 h1 = ..................................=    16.00 mm
                 b1 = ..................................=   174.00 mm
                 b1.h1 >= b.h
```

Local loads Shell Side Inlet I1, Loaded Area on cylindrical shell

WRC 107 Bulletin March 1979

Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Sign convention for loads and moments



Design pressure	1 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=134.67 MPa
Yield strength	202 MPa
Modulus of Elasticity	170,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Thickness Tr	16 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=136.5 mm

Geometric parameters

Mean radius $R_m = (R + T_r) - [(T_r + T_s - c)/2] = 667.5$ mm
Total thickness $T = T_r + T_s - c = 29$ mm
$\gamma = R_m / T = 23.017$
$\beta = 0.875\ r_o / R_m = 0.179$

Stress concentration factors

membrane Kn =1.782
bending Kb =1.482

Applied loads

Radial P = 1,105 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 3,058 daN.m
Bending moment ML = 1,560 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on Loaded Area

		Points							
	(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses								
(1)	Kn (Nx / P / Rm) . P/ (RmT)	2.88	2.88	2.88	2.88	3.76	3.76	3.76	3.76
(2)	Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-32.32	-32.32	32.32	32.32
(3)	Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-10.04	-10.04	10.04	10.04	0	0	0	0
(4)	= (1) + (2) + (3)	-7.16	-7.16	12.91	12.91	-28.56	-28.56	36.09	36.09
(5)	Pressure	25.48	25.48	25.48	25.48	25.48	25.48	25.48	25.48
(6)	= (4) + (5)	18.32	18.32	38.39	38.39	-3.08	-3.08	61.57	61.57
(7)	Kb (Mx / P) . 6 P/ T^2	11.22	-11.22	11.22	-11.22	7.13	-7.13	7.13	-7.13
(8)	Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-128.44	128.44	128.44	-128.44
(9)	Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-84.87	84.87	84.87	-84.87	0	0	0	0
(10)	= (7) + (8) + (9)	-73.65	73.65	96.1	-96.1	-121.31	121.31	135.57	-135.57
	Circumferential stresses								
(11)	Kn (Nϕ / P / Rm) . P/ Rm / T	3.76	3.76	3.76	3.76	2.88	2.88	2.88	2.88
(12)	Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-20.6	-20.6	20.6	20.6
(13)	Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-31.36	-31.36	31.36	31.36	0	0	0	0
(14)	= (11) + (12) + (13)	-27.6	-27.6	35.12	35.12	-17.72	-17.72	23.47	23.47
(15)	Pressure	50.96	50.96	50.96	50.96	50.96	50.96	50.96	50.96
(16)	= (14) + (15)	23.36	23.36	86.09	86.09	33.24	33.24	74.44	74.44
(17)	Kb (Mϕ / P) . 6 P/ T^2	7.22	-7.22	7.22	-7.22	10.93	-10.93	10.93	-10.93
(18)	Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-243.75	243.75	243.75	-243.75
(19)	Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-51.71	51.71	51.71	-51.71	0	0	0	0
(20)	= (17) + (18) + (19)	-44.49	44.49	58.93	-58.93	-232.82	232.82	254.68	-254.68
	Shear stresses								
(21)	Vc / Π ro T	0	0	0	0	0	0	0	0
(22)	VL / Π ro T	0	0	0	0	0	0	0	0
(23)	Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
	σx = (6) + (10)	-55.33	91.97	134.49	-57.7	-124.39	118.23	197.13	-74
	σϕ = (16) + (20)	-21.12	67.85	145.02	27.15	-199.58	266.06	329.12	-180.25
	τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24)	$(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-21.12	91.97	145.02	27.15	-124.39	266.06	329.12	-74
(25)	$(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-55.33	67.85	134.49	-57.7	-199.58	118.23	197.13	-180.25
(26)	= (24) – (25)	34.2	24.12	10.53	84.86	75.2	147.84	131.99	106.25
(27)	= (6) – (16)	-5.04	-5.04	-47.69	-47.69	-36.32	-36.32	-12.87	-12.87

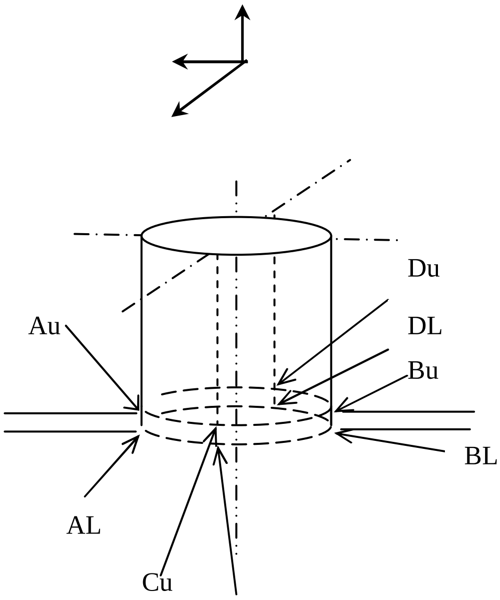
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 329.12 MPa	404 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 86.09 MPa	202 MPa (1.5 f)

β = 0.179		Read values	Used values
Fig. 3C Fig. 3C	γ=50 γ=15	4.8417 2.2277	**(Pts A,B) Nx/P/Rm = 2.8265**
Fig. 4C Fig. 4C	γ=25 γ=15	3.9751 2.5774	**(Pts C,D) Nx/P/Rm = 3.6979**
Fig. 4C Fig. 4C	γ=25 γ=15	3.9751 2.5774	**(Pts A,B) Nϕ/P/Rm = 3.6979**
Fig. 3C Fig. 3C	γ=50 γ=15	4.8417 2.2277	**(Pts C,D) Nϕ/P/Rm = 2.8265**
Fig. 2C-1 Fig. 2C-1	γ=25 γ=15	0.0583 0.0761	**(Pts A,B) Mϕ/P = 0.0618**
Fig. 1C Fig. 1C	γ=25 γ=15	0.0902 0.1072	**(Pts C,D) Mϕ/P = 0.0935**
Fig. 1C-1 Fig. 1C-1	γ=25 γ=15	0.0928 0.1091	**(Pts A,B) Mx/P = 0.0961**
Fig. 2C Fig. 2C	γ=25 γ=15	0.0575 0.0753	**(Pts C,D) Mx/P = 0.061**
Fig. 3A Fig. 3A	γ=25 γ=15	0.9615 0.5189	**Nϕ/(Mc/Rm2 β) = 0.8738**
Fig. 4A Fig. 4A	γ=25 γ=15	1.5146 0.791	**Nx/(Mc/Rm2 β) = 1.3711**
Fig. 1A Fig. 1A	γ=50 γ=15	0.0743 0.0947	**Mϕ/(Mc/Rm β) = 0.09**
Fig. 2A Fig. 2A	γ=25 γ=15	0.0463 0.0519	**Mx/(Mc/Rm β) = 0.0474**
Fig. 3B Fig. 3B	γ=25 γ=15	2.85 1.6284	**Nϕ/(ML/Rm2 β) = 2.6078**
Fig. 4B Fig. 4B	γ=25 γ=15	0.9199 0.4899	**Nx/(ML/Rm2 β) = 0.8346**
Fig. 1B Fig. 1B	γ=25 γ=15	0.0358 0.0441	**Mϕ/(ML/Rm β) = 0.0374**
Fig. 2B Fig. 2B	γ=25 γ=15	0.0594 0.0696	**Mx/(ML/Rm β) = 0.0614**

Local loads Shell Side Inlet I1, At the edge of reinforcing pad on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	1 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=134.67 MPa
Yield strength	202 MPa
Modulus of Elasticity	170,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Radius 310.5 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=310.5 mm

Geometric parameters

Mean radius Rm = R - [(Ts -c)/2] = 659.5 mm
Total thickness T = Ts - c = 13 mm
γ = Rm / T = 50.731
β = 0.875 ro / Rm = 0.412

Stress concentration factors

membrane Kn =1.48
bending Kb =1.23

Applied loads

Radial P = 1,105 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 3,058 daN.m
Bending moment ML = 1,560 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	2.74	2.74	2.74	2.74	7.39	7.39	7.39	7.39
(2) Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-93.61	-93.61	93.61	93.61
(3) Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-12.87	-12.87	12.87	12.87	0	0	0	0
(4) = (1) + (2) + (3)	-10.13	-10.13	15.61	15.61	-86.22	-86.22	101	101
(5) Pressure	25.48	25.48	25.48	25.48	25.48	25.48	25.48	25.48
(6) = (4) + (5)	15.35	15.35	41.1	41.1	-60.74	-60.74	126.48	126.48
(7) Kb (Mx / P) . 6 P/ T^2	8.16	-8.16	8.16	-8.16	1.92	-1.92	1.92	-1.92
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-115.26	115.26	115.26	-115.26
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-20.54	20.54	20.54	-20.54	0	0	0	0
(10) = (7) + (8) + (9)	-12.38	12.38	28.69	-28.69	-113.33	113.33	117.18	-117.18
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	7.39	7.39	7.39	7.39	2.74	2.74	2.74	2.74
(12) Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-23.94	-23.94	23.94	23.94
(13) Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-21.77	-21.77	21.77	21.77	0	0	0	0
(14) = (11) + (12) + (13)	-14.39	-14.39	29.16	29.16	-21.19	-21.19	26.68	26.68
(15) Pressure	50.96	50.96	50.96	50.96	50.96	50.96	50.96	50.96
(16) = (14) + (15)	36.58	36.58	80.12	80.12	29.77	29.77	77.64	77.64
(17) Kb (Mϕ / P) . 6 P/ T^2	3.33	-3.33	3.33	-3.33	10.01	-10.01	10.01	-10.01
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-289.48	289.48	289.48	-289.48
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-13.11	13.11	13.11	-13.11	0	0	0	0
(20) = (17) + (18) + (19)	-9.77	9.77	16.44	-16.44	-279.47	279.47	299.49	-299.49
Shear stresses								
(21) Vc / Π ro T	0	0	0	0	0	0	0	0
(22) VL / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	2.97	27.74	69.79	12.4	-174.07	52.59	243.66	9.3
σϕ = (16) + (20)	26.8	46.35	96.56	63.69	-249.71	309.24	377.13	-221.85
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	26.8	46.35	96.56	63.69	-174.07	309.24	377.13	9.3
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	2.97	27.74	69.79	12.4	-249.71	52.59	243.66	-221.85
(26) = (24) – (25)	23.83	18.61	26.77	51.28	75.63	256.65	133.47	231.14
(27) = (6) – (16)	-21.22	-21.22	-39.03	-39.03	-90.51	-90.51	48.84	48.84

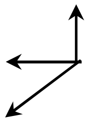
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 377.13 MPa	404 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 126.48 MPa	202 MPa (1.5 f)

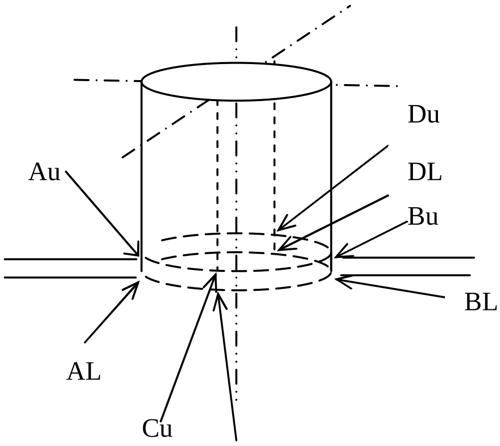
***β* = 0.412**		Read values	Used values
Fig. 3C Fig. 3C	γ=100 γ=50	1.54 1.4375	**(Pts A,B) Nx/P/Rm = 1.439**
Fig. 4C Fig. 4C	γ=75 γ=50	4.6749 3.8499	**(Pts C,D) Nx/P/Rm = 3.874**
Fig. 4C Fig. 4C	γ=75 γ=50	4.6749 3.8499	**(Pts A,B) Nϕ/P/Rm = 3.874**
Fig. 3C Fig. 3C	γ=100 γ=50	1.54 1.4375	**(Pts C,D) Nϕ/P/Rm = 1.439**
Fig. 2C-1 Fig. 2C-1	γ=75 γ=50	0.0046 0.007	**(Pts A,B) Mϕ/P = 0.0069**
Fig. 1C Fig. 1C	γ=75 γ=50	*0.0142* *0.0209*	**(Pts C,D) Mϕ/P = 0.0207**
Fig. 1C-1 Fig. 1C-1	γ=75 γ=50	0.0121 0.017	**(Pts A,B) Mx/P = 0.0169**
Fig. 2C Fig. 2C	γ=75 γ=50	*0.0022* *0.004*	**(Pts C,D) Mx/P = 0.004**
Fig. 3A Fig. 3A	γ=75 γ=50	1.3876 1.2276	**Nϕ/(Mc/Rm2 β) = 1.2323**
Fig. 4A Fig. 4A	γ=75 γ=50	6.3944 4.7715	**Nx/(Mc/Rm2 β) = 4.8189**
Fig. 1A Fig. 1A	γ=100 γ=50	0.053 0.059	**Mϕ/(Mc/Rm β) = 0.0589**
Fig. 2A Fig. 2A	γ=75 γ=50	0.022 0.0235	**Mx/(Mc/Rm β) = 0.0235**
Fig. 3B Fig. 3B	γ=75 γ=50	2.582 2.1856	**Nϕ/(ML/Rm2 β) = 2.1972**
Fig. 4B Fig. 4B	γ=75 γ=50	1.434 1.2947	**Nx/(ML/Rm2 β) = 1.2988**
Fig. 1B Fig. 1B	γ=75 γ=50	0.0037 0.0053	**Mϕ/(ML/Rm β) = 0.0052**
Fig. 2B Fig. 2B	γ=75 γ=50	0.0055 0.0083	**Mx/(ML/Rm β) = 0.0082**

Local loads Shell Side Inlet I1, Loaded Area on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments





Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	1 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=134.67 MPa
Yield strength	202 MPa
Modulus of Elasticity	170,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius R=666 mm
Thickness Ts=16 mm
Corrosion allowance c=3 mm

Reinforcing pad dimensions

Thickness Tr 16 mm

Dimensions of Loaded Area

Fillet radius 15.21 mm
External radius ro=136.5 mm

Geometric parameters

Mean radius Rm = (R + Tr) - [(Tr + Ts -c)/2] = 667.5 mm
Total thickness T = Tr + Ts - c = 29 mm
γ = Rm / T = 23.017
β = 0.875 ro / Rm = 0.179

Stress concentration factors

membrane Kn =1.782
bending Kb =1.482

Applied loads

Radial P = -1,105 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 3,058 daN.m
Bending moment ML = 1,560 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on Loaded Area

(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	-2.88	-2.88	-2.88	-2.88	-3.76	-3.76	-3.76	-3.76
(2) Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-32.32	-32.32	32.32	32.32
(3) Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-10.04	-10.04	10.04	10.04	0	0	0	0
(4) = (1) + (2) + (3)	-12.91	-12.91	7.16	7.16	-36.09	-36.09	28.56	28.56
(5) Pressure	25.48	25.48	25.48	25.48	25.48	25.48	25.48	25.48
(6) = (4) + (5)	12.57	12.57	32.64	32.64	-10.6	-10.6	54.04	54.04
(7) Kb (Mx / P) . 6 P/ T^2	-11.22	11.22	-11.22	11.22	-7.13	7.13	-7.13	7.13
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-128.44	128.44	128.44	-128.44
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-84.87	84.87	84.87	-84.87	0	0	0	0
(10) = (7) + (8) + (9)	-96.1	96.1	73.65	-73.65	-135.57	135.57	121.31	-121.31
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	-3.76	-3.76	-3.76	-3.76	-2.88	-2.88	-2.88	-2.88
(12) Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-20.6	-20.6	20.6	20.6
(13) Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-31.36	-31.36	31.36	31.36	0	0	0	0
(14) = (11) + (12) + (13)	-35.12	-35.12	27.6	27.6	-23.47	-23.47	17.72	17.72
(15) Pressure	50.96	50.96	50.96	50.96	50.96	50.96	50.96	50.96
(16) = (14) + (15)	15.84	15.84	78.56	78.56	27.49	27.49	68.68	68.68
(17) Kb (Mϕ / P) . 6 P/ T^2	-7.22	7.22	-7.22	7.22	-10.93	10.93	-10.93	10.93
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-243.75	243.75	243.75	-243.75
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-51.71	51.71	51.71	-51.71	0	0	0	0
(20) = (17) + (18) + (19)	-58.93	58.93	44.49	-44.49	-254.68	254.68	232.82	-232.82
Shear stresses								
(21) Vc / Π ro T	0	0	0	0	0	0	0	0
(22) VL / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	-83.53	108.66	106.29	-41.01	-146.17	124.96	175.35	-67.27
σϕ = (16) + (20)	-43.09	74.77	123.05	34.07	-227.2	282.17	301.51	-164.14
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-43.09	108.66	123.05	34.07	-146.17	282.17	301.51	-67.27
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-83.53	74.77	106.29	-41.01	-227.2	124.96	175.35	-164.14
(26) = (24) – (25)	40.43	33.89	16.76	75.08	81.03	157.21	126.16	96.87
(27) = (6) – (16)	-3.27	-3.27	-45.92	-45.92	-38.09	-38.09	-14.64	-14.64

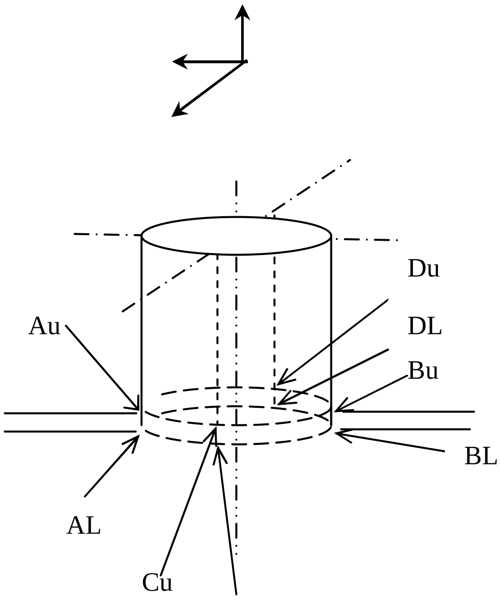
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 301.51 MPa	404 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 78.56 MPa	202 MPa (1.5 f)

***β* = 0.179**		Read values	Used values
Fig. 3C Fig. 3C	γ=50 γ=15	4.8417 2.2277	**(Pts A,B) Nx/P/Rm = 2.8265**
Fig. 4C Fig. 4C	γ=25 γ=15	3.9751 2.5774	**(Pts C,D) Nx/P/Rm = 3.6979**
Fig. 4C Fig. 4C	γ=25 γ=15	3.9751 2.5774	**(Pts A,B) Nϕ/P/Rm = 3.6979**
Fig. 3C Fig. 3C	γ=50 γ=15	4.8417 2.2277	**(Pts C,D) Nϕ/P/Rm = 2.8265**
Fig. 2C-1 Fig. 2C-1	γ=25 γ=15	0.0583 0.0761	**(Pts A,B) Mϕ/P = 0.0618**
Fig. 1C Fig. 1C	γ=25 γ=15	0.0902 0.1072	**(Pts C,D) Mϕ/P = 0.0935**
Fig. 1C-1 Fig. 1C-1	γ=25 γ=15	0.0928 0.1091	**(Pts A,B) Mx/P = 0.0961**
Fig. 2C Fig. 2C	γ=25 γ=15	0.0575 0.0753	**(Pts C,D) Mx/P = 0.061**
Fig. 3A Fig. 3A	γ=25 γ=15	0.9615 0.5189	**Nϕ/(Mc/Rm2 β) = 0.8738**
Fig. 4A Fig. 4A	γ=25 γ=15	1.5146 0.791	**Nx/(Mc/Rm2 β) = 1.3711**
Fig. 1A Fig. 1A	γ=50 γ=15	0.0743 0.0947	**Mϕ/(Mc/Rm β) = 0.09**
Fig. 2A Fig. 2A	γ=25 γ=15	0.0463 0.0519	**Mx/(Mc/Rm β) = 0.0474**
Fig. 3B Fig. 3B	γ=25 γ=15	2.85 1.6284	**Nϕ/(ML/Rm2 β) = 2.6078**
Fig. 4B Fig. 4B	γ=25 γ=15	0.9199 0.4899	**Nx/(ML/Rm2 β) = 0.8346**
Fig. 1B Fig. 1B	γ=25 γ=15	0.0358 0.0441	**Mϕ/(ML/Rm β) = 0.0374**
Fig. 2B Fig. 2B	γ=25 γ=15	0.0594 0.0696	**Mx/(ML/Rm β) = 0.0614**

Local loads Shell Side Inlet I1, At the edge of reinforcing pad on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	1 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=134.67 MPa
Yield strength	202 MPa
Modulus of Elasticity	170,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Radius	310.5 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=310.5 mm

Geometric parameters

Mean radius Rm = R - [(Ts -c)/2] = 659.5 mm
Total thickness T = Ts - c = 13 mm
γ = Rm / T = 50.731
β = 0.875 ro / Rm = 0.412

Stress concentration factors

membrane Kn =1.48
bending Kb =1.23

Applied loads

Radial P = -1,105 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 3,058 daN.m
Bending moment ML = 1,560 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

		Points							
	(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses								
(1)	Kn (Nx / P / Rm) . P/ (RmT)	-2.74	-2.74	-2.74	-2.74	-7.39	-7.39	-7.39	-7.39
(2)	Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-93.61	-93.61	93.61	93.61
(3)	Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-12.87	-12.87	12.87	12.87	0	0	0	0
(4)	= (1) + (2) + (3)	-15.61	-15.61	10.13	10.13	-101	-101	86.22	86.22
(5)	Pressure	25.48	25.48	25.48	25.48	25.48	25.48	25.48	25.48
(6)	= (4) + (5)	9.87	9.87	35.61	35.61	-75.52	-75.52	111.7	111.7
(7)	Kb (Mx / P) . 6 P/ T^2	-8.16	8.16	-8.16	8.16	-1.92	1.92	-1.92	1.92
(8)	Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-115.26	115.26	115.26	-115.26
(9)	Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-20.54	20.54	20.54	-20.54	0	0	0	0
(10)	= (7) + (8) + (9)	-28.69	28.69	12.38	-12.38	-117.18	117.18	113.33	-113.33
	Circumferential stresses								
(11)	Kn (Nϕ / P / Rm) . P/ Rm / T	-7.39	-7.39	-7.39	-7.39	-2.74	-2.74	-2.74	-2.74
(12)	Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-23.94	-23.94	23.94	23.94
(13)	Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-21.77	-21.77	21.77	21.77	0	0	0	0
(14)	= (11) + (12) + (13)	-29.16	-29.16	14.39	14.39	-26.68	-26.68	21.19	21.19
(15)	Pressure	50.96	50.96	50.96	50.96	50.96	50.96	50.96	50.96
(16)	= (14) + (15)	21.8	21.8	65.35	65.35	24.28	24.28	72.16	72.16
(17)	Kb (Mϕ / P) . 6 P/ T^2	-3.33	3.33	-3.33	3.33	-10.01	10.01	-10.01	10.01
(18)	Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-289.48	289.48	289.48	-289.48
(19)	Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-13.11	13.11	13.11	-13.11	0	0	0	0
(20)	= (17) + (18) + (19)	-16.44	16.44	9.77	-9.77	-299.49	299.49	279.47	-279.47
	Shear stresses								
(21)	Vc / Π ro T	0	0	0	0	0	0	0	0
(22)	VL / Π ro T	0	0	0	0	0	0	0	0
(23)	Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
	σx = (6) + (10)	-18.83	38.56	47.99	23.23	-192.7	41.67	225.04	-1.63
	σϕ = (16) + (20)	5.36	38.24	75.12	55.57	-275.21	323.77	351.63	-207.32
	τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24)	$(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ /\ 2$	5.36	38.56	75.12	55.57	-192.7	323.77	351.63	-1.63
(25)	$(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ /\ 2$	-18.83	38.24	47.99	23.23	-275.21	41.67	225.04	-207.32
(26)	= (24) – (25)	24.19	0.32	27.13	32.35	82.51	282.1	126.59	205.69
(27)	= (6) – (16)	-11.93	-11.93	-29.74	-29.74	-99.8	-99.8	39.55	39.55

	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 351.63 MPa	404 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 111.7 MPa	202 MPa (1.5 f)

β = 0.412		Read values	Used values
Fig. 3C Fig. 3C	γ=100 γ=50	1.54 1.4375	**(Pts A,B) Nx/P/Rm = 1.439**
Fig. 4C Fig. 4C	γ=75 γ=50	4.6749 3.8499	**(Pts C,D) Nx/P/Rm = 3.874**
Fig. 4C Fig. 4C	γ=75 γ=50	4.6749 3.8499	**(Pts A,B) Nϕ/P/Rm = 3.874**
Fig. 3C Fig. 3C	γ=100 γ=50	1.54 1.4375	**(Pts C,D) Nϕ/P/Rm = 1.439**
Fig. 2C-1 Fig. 2C-1	γ=75 γ=50	0.0046 0.007	**(Pts A,B) Mϕ/P = 0.0069**
Fig. 1C Fig. 1C	γ=75 γ=50	*0.0142* *0.0209*	**(Pts C,D) Mϕ/P = 0.0207**
Fig. 1C-1 Fig. 1C-1	γ=75 γ=50	0.0121 0.017	**(Pts A,B) Mx/P = 0.0169**
Fig. 2C Fig. 2C	γ=75 γ=50	*0.0022* *0.004*	**(Pts C,D) Mx/P = 0.004**
Fig. 3A Fig. 3A	γ=75 γ=50	1.3876 1.2276	**Nϕ/(Mc/Rm2 β) = 1.2323**
Fig. 4A Fig. 4A	γ=75 γ=50	6.3944 4.7715	**Nx/(Mc/Rm2 β) = 4.8189**
Fig. 1A Fig. 1A	γ=100 γ=50	0.053 0.059	**Mϕ/(Mc/Rm β) = 0.0589**
Fig. 2A Fig. 2A	γ=75 γ=50	0.022 0.0235	**Mx/(Mc/Rm β) = 0.0235**
Fig. 3B Fig. 3B	γ=75 γ=50	2.582 2.1856	**Nϕ/(ML/Rm2 β) = 2.1972**
Fig. 4B Fig. 4B	γ=75 γ=50	1.434 1.2947	**Nx/(ML/Rm2 β) = 1.2988**
Fig. 1B Fig. 1B	γ=75 γ=50	0.0037 0.0053	**Mϕ/(ML/Rm β) = 0.0052**
Fig. 2B Fig. 2B	γ=75 γ=50	0.0055 0.0083	**Mx/(ML/Rm β) = 0.0082**

Opening reinforcement O1 int. pressure Shell Side Outlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
DESIGN PRESSURE P              1.0000 MPa
TEMPERATURE                    400.0  °C
CORROSION SHELL C /NOZZLE CT                        3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                134.67 /     134.67 MPa
          PAD R                                                134.67 MPa
JOINT EFFICIENCY V                                  1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT            1332.00 /     168.30 mm
THICKNESS SHELL E / NOZZLE ET                      16.00 /      11.00 mm
NOZZLE SCHEDULE
FLANGE RATING                  300.   lb
NOZZLE HEIGHT  H               204.00 mm
NOZZLE INTERNAL HEIGHT M         0.00 mm
FLANGE HEIGHT EB                98.55 mm
REINFORCEMENT WIDTH LR          86.00 mm
REINFORCEMENT THICKNESS ER      16.00 mm
ECCENTRICITY                     0.00 mm
NOZZLE SLOPE ANGLE A             0.00 °

VESSEL in OPERATION            * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2*T+P).......................=      0.62 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ..................................=      0.00 mm
                 sA = E+h ..............................=     16.00 mm
                 sS = ET ...............................=     11.00 mm
                 di = (DT-2*(ET-CT)) ...................=    152.30 mm
                 Di = D-2*(E-C).........................=   1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    130.95 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=     44.76 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    130.95 mm
                 lSr=...................................=     44.76 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     1702. mm²
                 As1 = .................................=      462. mm²
                 As2 = .................................=     1376. mm²
                 Ap = ..................................=   144857. mm²
                 P*[Ap/(As0+As1+As2)+1/2]               =     41.42 MPa
                                                   <= S =    134.67 MPa

                 h1 = ..................................=     16.00 mm
                 b1 = ..................................=     86.00 mm
                 b1.h1 >= b.h
```

Opening reinforcement O1 int. pressure Shell Side Outlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
DESIGN PRESSURE P              2.1477 MPa
TEMPERATURE                     20.0  °C
CORROSION SHELL C /NOZZLE CT                       3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                               328.57 /     328.57 MPa
          PAD R                                               328.57 MPa
JOINT EFFICIENCY V                                 1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT           1332.00 /     168.30 mm
THICKNESS SHELL E / NOZZLE ET                     16.00 /      11.00 mm
NOZZLE SCHEDULE
FLANGE RATING                  300.   lb
NOZZLE HEIGHT  H               204.00 mm
NOZZLE INTERNAL HEIGHT M         0.00 mm
FLANGE HEIGHT EB                98.55 mm
REINFORCEMENT WIDTH LR          86.00 mm
REINFORCEMENT THICKNESS ER      16.00 mm
ECCENTRICITY                     0.00 mm
NOZZLE SLOPE ANGLE A             0.00 °

VESSEL in TEST                 * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2*T+P).......................=      0.55 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ..................................=      0.00 mm
                 sA = E+h ..............................=     16.00 mm
                 sS = ET ...............................=     11.00 mm
                 di = (DT-2*(ET-CT)) ...................=    152.30 mm
                 Di = D-2*(E-C).........................=   1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    130.95 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=     44.76 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    130.95 mm
                 lSr=...................................=     44.76 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     1702. mm²
                 As1 = .................................=      462. mm²
                 As2 = .................................=     1376. mm²
                 Ap = ..................................=   144857. mm²
                 P*[Ap/(As0+As1+As2)+1/2]               =     88.95 MPa
                                                   <= S =    328.57 MPa

                 h1 = ..................................=     16.00 mm
                 b1 = ..................................=     86.00 mm
                 b1.h1 >= b.h
```

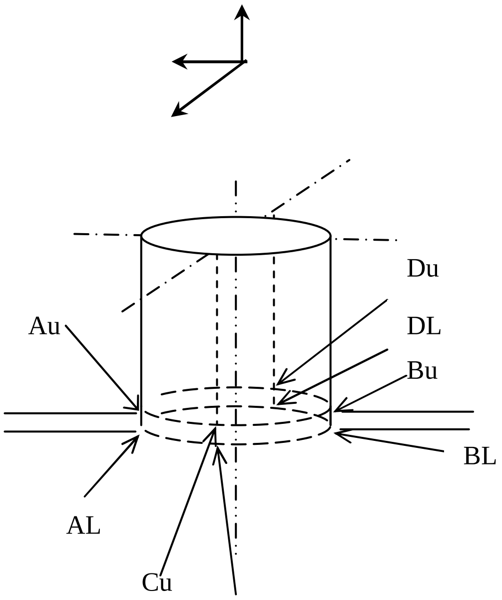
Opening reinforcement O1 ext. pressure Shell Side Outlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
EXT. PRESSURE                 0.1030 MPa
TEMPERATURE                   400.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 178.78 /     178.78 MPa
          PAD R                                                 178.78 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT             1332.00 /     168.30 mm
THICKNESS SHELL E / NOZZLE ET                       16.00 /      11.00 mm
NOZZLE SCHEDULE
FLANGE RATING                 300.   lb
NOZZLE HEIGHT  H              204.00 mm
NOZZLE INTERNAL HEIGHT M        0.00 mm
FLANGE HEIGHT EB               98.55 mm
REINFORCEMENT WIDTH LR         86.00 mm
REINFORCEMENT THICKNESS ER     16.00 mm
ECCENTRICITY                    0.00 mm
NOZZLE SLOPE ANGLE A            0.00 °

VESSEL in EXTERNAL PRESSURE    * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =..................................=      0.59 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ..................................=      0.00 mm
                 sA = E+h ..............................=     16.00 mm
                 sS = ET ...............................=     11.00 mm
                 di = (DT-2*(ET-CT)) ...................=    152.30 mm
                 Di = D-2*(E-C).........................=   1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    130.95 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=     44.76 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    130.95 mm
                 lSr=...................................=     44.76 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     1702. mm^2
                 As1 = .................................=      462. mm^2
                 As2 = .................................=     1376. mm^2
                 Ap = ..................................=   144857. mm^2
                 P*[Ap/(As0+As1+As2)+1/2]               =      4.27 MPa
                                                   <= S =    178.78 MPa

                 h1 = ..................................=     16.00 mm
                 b1 = ..................................=     86.00 mm
                 b1.h1 >= b.h
```

Local loads Shell Side Outlet O1, Loaded Area on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	1 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=134.67 MPa
Yield strength	202 MPa
Modulus of Elasticity	170,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Thickness Tr	16 mm

Dimensions of Loaded Area

Fillet radius	13.52 mm
External radius	ro=84.15 mm

Geometric parameters

Mean radius Rm = (R + Tr) - [(Tr + Ts -c)/2] = 667.5 mm
Total thickness T = Tr + Ts - c = 29 mm
γ = Rm / T = 23.017
β = 0.875 ro / Rm = 0.11

Stress concentration factors

membrane Kn =1.847
bending Kb =1.538

Applied loads

Radial P = 442 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 925 daN.m
Bending moment ML = 713 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on Loaded Area

(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	1.54	1.54	1.54	1.54	1.77	1.77	1.77	1.77
(2) Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-10.31	-10.31	10.31	10.31
(3) Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-5.45	-5.45	5.45	5.45	0	0	0	0
(4) = (1) + (2) + (3)	-3.9	-3.9	6.99	6.99	-8.54	-8.54	12.08	12.08
(5) Pressure	25.48	25.48	25.48	25.48	25.48	25.48	25.48	25.48
(6) = (4) + (5)	21.58	21.58	32.47	32.47	16.94	16.94	37.56	37.56
(7) Kb (Mx / P) . 6 P/ T^2	6.95	-6.95	6.95	-6.95	5.08	-5.08	5.08	-5.08
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-74.62	74.62	74.62	-74.62
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-87.18	87.18	87.18	-87.18	0	0	0	0
(10) = (7) + (8) + (9)	-80.23	80.23	94.13	-94.13	-69.55	69.55	79.7	-79.7
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	1.77	1.77	1.77	1.77	1.54	1.54	1.54	1.54
(12) Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-7.39	-7.39	7.39	7.39
(13) Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-19.56	-19.56	19.56	19.56	0	0	0	0
(14) = (11) + (12) + (13)	-17.79	-17.79	21.32	21.32	-5.85	-5.85	8.94	8.94
(15) Pressure	50.96	50.96	50.96	50.96	50.96	50.96	50.96	50.96
(16) = (14) + (15)	33.17	33.17	72.29	72.29	45.11	45.11	59.9	59.9
(17) Kb (Mϕ / P) . 6 P/ T^2	5.09	-5.09	5.09	-5.09	6.94	-6.94	6.94	-6.94
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-137.89	137.89	137.89	-137.89
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-52.17	52.17	52.17	-52.17	0	0	0	0
(20) = (17) + (18) + (19)	-47.08	47.08	57.26	-57.26	-130.95	130.95	144.83	-144.83
Shear stresses								
(21) Vc / Π ro T	0	0	0	0	0	0	0	0
(22) VL / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	-58.66	101.81	126.6	-61.66	-52.61	86.48	117.26	-42.14
σϕ = (16) + (20)	-13.9	80.25	129.54	15.03	-85.84	176.06	204.73	-84.93
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-13.9	101.81	129.54	15.03	-52.61	176.06	204.73	-42.14
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-58.66	80.25	126.6	-61.66	-85.84	86.48	117.26	-84.93
(26) = (24) – (25)	44.75	21.56	2.94	76.69	33.23	89.58	87.47	42.79
(27) = (6) – (16)	-11.59	-11.59	-39.81	-39.81	-28.17	-28.17	-22.34	-22.34

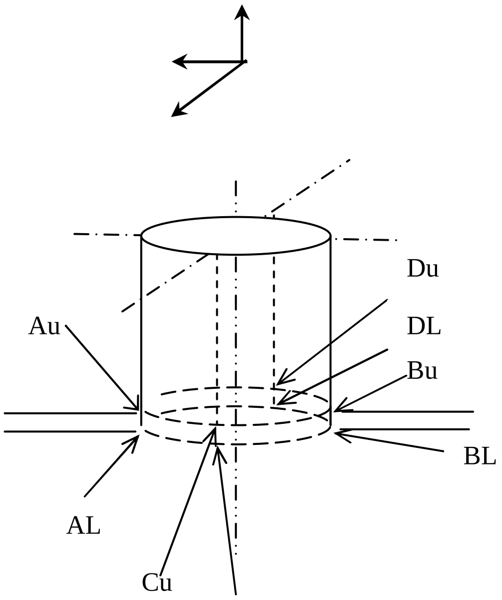
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 204.73 MPa	404 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 72.29 MPa	202 MPa (1.5 f)

β = 0.11		Read values	Used values
Fig. 3C	γ=50	6.9886	
Fig. 3C	γ=15	2.6726	**(Pts A,B) Nx/P/Rm = 3.6612**
Fig. 4C	γ=25	4.5274	
Fig. 4C	γ=15	2.8289	**(Pts C,D) Nx/P/Rm = 4.1906**
Fig. 4C	γ=25	4.5274	
Fig. 4C	γ=15	2.8289	**(Pts A,B) Nϕ/P/Rm = 4.1906**
Fig. 3C	γ=50	6.9886	
Fig. 3C	γ=15	2.6726	**(Pts C,D) Nϕ/P/Rm = 3.6612**
Fig. 2C-1	γ=25	0.101	
Fig. 2C-1	γ=15	0.1208	**(Pts A,B) Mϕ/P = 0.105**
Fig. 1C	γ=25	0.1392	
Fig. 1C	γ=15	0.1591	**(Pts C,D) Mϕ/P = 0.1432**
Fig. 1C-1	γ=25	0.1403	
Fig. 1C-1	γ=15	0.1553	**(Pts A,B) Mx/P = 0.1433**
Fig. 2C	γ=25	0.1009	
Fig. 2C	γ=15	0.1203	**(Pts C,D) Mx/P = 0.1047**
Fig. 3A	γ=25	0.6884	
Fig. 3A	γ=15	0.3269	**Nϕ/(Mc/Rm2 β) = 0.6168**
Fig. 4A	γ=25	0.9589	
Fig. 4A	γ=15	0.4605	**Nx/(Mc/Rm2 β) = 0.8601**
Fig. 1A	γ=50	0.0909	
Fig. 1A	γ=15	0.1028	**Mϕ/(Mc/Rm β) = 0.1001**
Fig. 2A	γ=25	0.053	
Fig. 2A	γ=15	0.0588	**Mx/(Mc/Rm β) = 0.0541**
Fig. 3B	γ=25	2.3438	
Fig. 3B	γ=15	1.1978	**Nϕ/(ML/Rm2 β) = 2.1166**
Fig. 4B	γ=25	0.6602	
Fig. 4B	γ=15	0.304	**Nx/(ML/Rm2 β) = 0.5895**
Fig. 1B	γ=25	0.0478	
Fig. 1B	γ=15	0.0543	**Mϕ/(ML/Rm β) = 0.0491**
Fig. 2B	γ=25	0.0809	
Fig. 2B	γ=15	0.0869	**Mx/(ML/Rm β) = 0.0821**

Local loads Shell Side Outlet O1, At the edge of reinforcing pad on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	1 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=134.67 MPa
Yield strength	202 MPa
Modulus of Elasticity	170,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius R=666 mm
Thickness Ts=16 mm
Corrosion allowance c=3 mm

Reinforcing pad dimensions

Radius 170.15 mm

Dimensions of Loaded Area

Fillet radius 13.52 mm
External radius ro=170.15 mm

Geometric parameters

Mean radius Rm = R - [(Ts -c)/2] = 659.5 mm
Total thickness T = Ts - c = 13 mm
γ = Rm / T = 50.731
β = 0.875 ro / Rm = 0.226

Stress concentration factors

membrane Kn =1.532
bending Kb =1.282

Applied loads

Radial P = 442 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 925 daN.m
Bending moment ML = 713 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

	Points							
(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	2.89	2.89	2.89	2.89	5.04	5.04	5.04	5.04
(2) Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-49.88	-49.88	49.88	49.88
(3) Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-17.59	-17.59	17.59	17.59	0	0	0	0
(4) = (1) + (2) + (3)	-14.7	-14.7	20.48	20.48	-44.84	-44.84	54.92	54.92
(5) Pressure	25.48	25.48	25.48	25.48	25.48	25.48	25.48	25.48
(6) = (4) + (5)	10.78	10.78	45.96	45.96	-19.36	-19.36	80.4	80.4
(7) Kb (Mx / P) . 6 P/ T^2	10.27	-10.27	10.27	-10.27	4.51	-4.51	4.51	-4.51
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-85.07	85.07	85.07	-85.07
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-54.23	54.23	54.23	-54.23	0	0	0	0
(10) = (7) + (8) + (9)	-43.96	43.96	64.49	-64.49	-80.56	80.56	89.59	-89.59
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	5.04	5.04	5.04	5.04	2.89	2.89	2.89	2.89
(12) Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-21.7	-21.7	21.7	21.7
(13) Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-38.59	-38.59	38.59	38.59	0	0	0	0
(14) = (11) + (12) + (13)	-33.55	-33.55	43.63	43.63	-18.81	-18.81	24.59	24.59
(15) Pressure	50.96	50.96	50.96	50.96	50.96	50.96	50.96	50.96
(16) = (14) + (15)	17.41	17.41	94.6	94.6	32.15	32.15	75.56	75.56
(17) Kb (Mϕ / P) . 6 P/ T^2	4.83	-4.83	4.83	-4.83	11	-11	11	-11
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-189.89	189.89	189.89	-189.89
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-37.21	37.21	37.21	-37.21	0	0	0	0
(20) = (17) + (18) + (19)	-32.38	32.38	42.05	-42.05	-178.89	178.89	200.89	-200.89
Shear stresses								
(21) Vc / Π ro T	0	0	0	0	0	0	0	0
(22) VL / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	-33.18	54.74	110.46	-18.53	-99.91	61.2	169.99	-9.19
σϕ = (16) + (20)	-14.97	49.79	136.64	52.55	-146.74	211.04	276.45	-125.33
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-14.97	54.74	136.64	52.55	-99.91	211.04	276.45	-9.19
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-33.18	49.79	110.46	-18.53	-146.74	61.2	169.99	-125.33
(26) = (24) – (25)	18.21	4.95	26.19	71.08	46.82	149.84	106.46	116.15
(27) = (6) – (16)	-6.63	-6.63	-48.63	-48.63	-51.51	-51.51	4.84	4.84

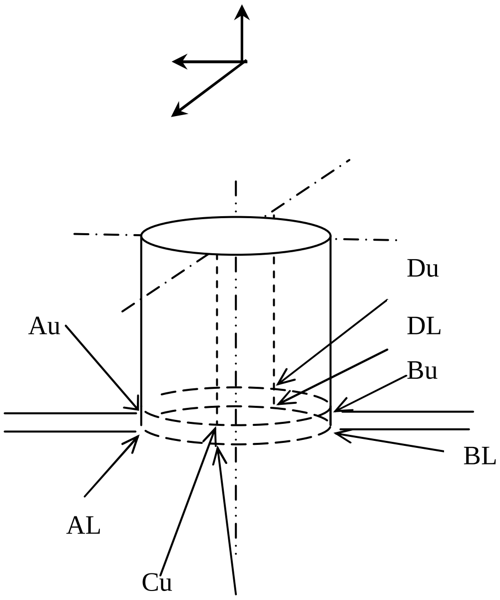
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 276.45 MPa	404 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 94.6 MPa	202 MPa (1.5 f)

***β* = 0.226**		Read values	Used values
Fig. 3C Fig. 3C	γ=100 γ=50	4.3588 3.6487	**(Pts A,B) Nx/P/Rm = 3.6591**
Fig. 4C Fig. 4C	γ=75 γ=50	8.3487 6.3201	**(Pts C,D) Nx/P/Rm = 6.3794**
Fig. 4C Fig. 4C	γ=75 γ=50	8.3487 6.3201	**(Pts A,B) Nϕ/P/Rm = 6.3794**
Fig. 3C Fig. 3C	γ=100 γ=50	4.3588 3.6487	**(Pts C,D) Nϕ/P/Rm = 3.6591**
Fig. 2C-1 Fig. 2C-1	γ=75 γ=50	0.0177 0.0242	**(Pts A,B) Mϕ/P = 0.024**
Fig. 1C Fig. 1C	γ=75 γ=50	*0.0446* *0.055*	**(Pts C,D) Mϕ/P = 0.0547**
Fig. 1C-1 Fig. 1C-1	γ=75 γ=50	0.0409 0.0513	**(Pts A,B) Mx/P = 0.051**
Fig. 2C Fig. 2C	γ=75 γ=50	*0.0161* *0.0226*	**(Pts C,D) Mx/P = 0.0224**
Fig. 3A Fig. 3A	γ=75 γ=50	2.5799 1.9355	**Nϕ/(Mc/Rm2 β) = 1.9543**
Fig. 4A Fig. 4A	γ=75 γ=50	6.9628 4.4171	**Nx/(Mc/Rm2 β) = 4.4915**
Fig. 1A Fig. 1A	γ=100 γ=50	0.0564 0.0673	**Mϕ/(Mc/Rm β) = 0.0671**
Fig. 2A Fig. 2A	γ=75 γ=50	0.0258 0.0302	**Mx/(Mc/Rm β) = 0.0301**
Fig. 3B Fig. 3B	γ=75 γ=50	5.614 4.4754	**Nϕ/(ML/Rm2 β) = 4.5087**
Fig. 4B Fig. 4B	γ=75 γ=50	2.8501 2.0311	**Nx/(ML/Rm2 β) = 2.055**
Fig. 1B Fig. 1B	γ=75 γ=50	0.0126 0.0172	**Mϕ/(ML/Rm β) = 0.0171**
Fig. 2B Fig. 2B	γ=75 γ=50	0.0167 0.0251	**Mx/(ML/Rm β) = 0.0249**

Local loads Shell Side Outlet O1, Loaded Area on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	1 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=134.67 MPa
Yield strength	202 MPa
Modulus of Elasticity	170,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Thickness Tr	16 mm

Dimensions of Loaded Area

Fillet radius	13.52 mm
External radius	ro=84.15 mm

Geometric parameters

Mean radius Rm = (R + Tr) - [(Tr + Ts -c)/2] = 667.5 mm
Total thickness T = Tr + Ts - c = 29 mm
γ = Rm / T = 23.017
β = 0.875 ro / Rm = 0.11

Stress concentration factors

membrane Kn =1.847
bending Kb =1.538

Applied loads

Radial P = -442 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 925 daN.m
Bending moment ML = 713 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on Loaded Area

(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	-1.54	-1.54	-1.54	-1.54	-1.77	-1.77	-1.77	-1.77
(2) Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-10.31	-10.31	10.31	10.31
(3) Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-5.45	-5.45	5.45	5.45	0	0	0	0
(4) = (1) + (2) + (3)	-6.99	-6.99	3.9	3.9	-12.08	-12.08	8.54	8.54
(5) Pressure	25.48	25.48	25.48	25.48	25.48	25.48	25.48	25.48
(6) = (4) + (5)	18.49	18.49	29.38	29.38	13.4	13.4	34.02	34.02
(7) Kb (Mx / P) . 6 P/ T^2	-6.95	6.95	-6.95	6.95	-5.08	5.08	-5.08	5.08
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-74.62	74.62	74.62	-74.62
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-87.18	87.18	87.18	-87.18	0	0	0	0
(10) = (7) + (8) + (9)	-94.13	94.13	80.23	-80.23	-79.7	79.7	69.55	-69.55
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	-1.77	-1.77	-1.77	-1.77	-1.54	-1.54	-1.54	-1.54
(12) Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-7.39	-7.39	7.39	7.39
(13) Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-19.56	-19.56	19.56	19.56	0	0	0	0
(14) = (11) + (12) + (13)	-21.32	-21.32	17.79	17.79	-8.94	-8.94	5.85	5.85
(15) Pressure	50.96	50.96	50.96	50.96	50.96	50.96	50.96	50.96
(16) = (14) + (15)	29.64	29.64	68.75	68.75	42.02	42.02	56.81	56.81
(17) Kb (Mϕ / P) . 6 P/ T^2	-5.09	5.09	-5.09	5.09	-6.94	6.94	-6.94	6.94
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-137.89	137.89	137.89	-137.89
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-52.17	52.17	52.17	-52.17	0	0	0	0
(20) = (17) + (18) + (19)	-57.26	57.26	47.08	-47.08	-144.83	144.83	130.95	-130.95
Shear stresses								
(21) Vc / Π ro T	0	0	0	0	0	0	0	0
(22) VL / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	-75.64	112.62	109.62	-50.85	-66.3	93.1	103.57	-35.52
σϕ = (16) + (20)	-27.62	86.89	115.83	21.67	-102.81	186.86	187.76	-74.14
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-27.62	112.62	115.83	21.67	-66.3	186.86	187.76	-35.52
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-75.64	86.89	109.62	-50.85	-102.81	93.1	103.57	-74.14
(26) = (24) – (25)	48.02	25.72	6.21	72.52	36.51	93.75	84.19	38.61
(27) = (6) – (16)	-11.15	-11.15	-39.37	-39.37	-28.62	-28.62	-22.79	-22.79

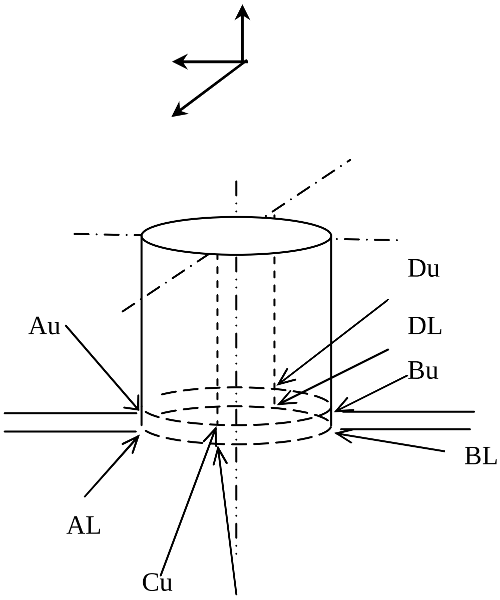
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 187.76 MPa	404 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 68.75 MPa	202 MPa (1.5 f)

***β* = 0.11**		Read values	Used values
Fig. 3C	γ=50	6.9886	
Fig. 3C	γ=15	2.6726	**(Pts A,B) Nx/P/Rm = 3.6612**
Fig. 4C	γ=25	4.5274	
Fig. 4C	γ=15	2.8289	**(Pts C,D) Nx/P/Rm = 4.1906**
Fig. 4C	γ=25	4.5274	
Fig. 4C	γ=15	2.8289	**(Pts A,B) Nϕ/P/Rm = 4.1906**
Fig. 3C	γ=50	6.9886	
Fig. 3C	γ=15	2.6726	**(Pts C,D) Nϕ/P/Rm = 3.6612**
Fig. 2C-1	γ=25	0.101	
Fig. 2C-1	γ=15	0.1208	**(Pts A,B) Mϕ/P = 0.105**
Fig. 1C	γ=25	0.1392	
Fig. 1C	γ=15	0.1591	**(Pts C,D) Mϕ/P = 0.1432**
Fig. 1C-1	γ=25	0.1403	
Fig. 1C-1	γ=15	0.1553	**(Pts A,B) Mx/P = 0.1433**
Fig. 2C	γ=25	0.1009	
Fig. 2C	γ=15	0.1203	**(Pts C,D) Mx/P = 0.1047**
Fig. 3A	γ=25	0.6884	
Fig. 3A	γ=15	0.3269	**Nϕ/(Mc/Rm2 β) = 0.6168**
Fig. 4A	γ=25	0.9589	
Fig. 4A	γ=15	0.4605	**Nx/(Mc/Rm2 β) = 0.8601**
Fig. 1A	γ=50	0.0909	
Fig. 1A	γ=15	0.1028	**Mϕ/(Mc/Rm β) = 0.1001**
Fig. 2A	γ=25	0.053	
Fig. 2A	γ=15	0.0588	**Mx/(Mc/Rm β) = 0.0541**
Fig. 3B	γ=25	2.3438	
Fig. 3B	γ=15	1.1978	**Nϕ/(ML/Rm2 β) = 2.1166**
Fig. 4B	γ=25	0.6602	
Fig. 4B	γ=15	0.304	**Nx/(ML/Rm2 β) = 0.5895**
Fig. 1B	γ=25	0.0478	
Fig. 1B	γ=15	0.0543	**Mϕ/(ML/Rm β) = 0.0491**
Fig. 2B	γ=25	0.0809	
Fig. 2B	γ=15	0.0869	**Mx/(ML/Rm β) = 0.0821**

Local loads Shell Side Outlet O1, At the edge of reinforcing pad on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	1 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=134.67 MPa
Yield strength	202 MPa
Modulus of Elasticity	170,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius R=666 mm
Thickness Ts=16 mm
Corrosion allowance c=3 mm

Reinforcing pad dimensions

Radius 170.15 mm

Dimensions of Loaded Area

Fillet radius 13.52 mm
External radius ro=170.15 mm

Geometric parameters

Mean radius Rm = R - [(Ts -c)/2] = 659.5 mm
Total thickness T = Ts - c = 13 mm
γ = Rm / T = 50.731
β = 0.875 ro / Rm = 0.226

Stress concentration factors

membrane Kn =1.532
bending Kb =1.282

Applied loads

Radial P = -442 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 925 daN.m
Bending moment ML = 713 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	-2.89	-2.89	-2.89	-2.89	-5.04	-5.04	-5.04	-5.04
(2) Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-49.88	-49.88	49.88	49.88
(3) Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-17.59	-17.59	17.59	17.59	0	0	0	0
(4) = (1) + (2) + (3)	-20.48	-20.48	14.7	14.7	-54.92	-54.92	44.84	44.84
(5) Pressure	25.48	25.48	25.48	25.48	25.48	25.48	25.48	25.48
(6) = (4) + (5)	5	5	40.18	40.18	-29.44	-29.44	70.32	70.32
(7) Kb (Mx / P) . 6 P/ T^2	-10.27	10.27	-10.27	10.27	-4.51	4.51	-4.51	4.51
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-85.07	85.07	85.07	-85.07
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-54.23	54.23	54.23	-54.23	0	0	0	0
(10) = (7) + (8) + (9)	-64.49	64.49	43.96	-43.96	-89.59	89.59	80.56	-80.56
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	-5.04	-5.04	-5.04	-5.04	-2.89	-2.89	-2.89	-2.89
(12) Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-21.7	-21.7	21.7	21.7
(13) Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-38.59	-38.59	38.59	38.59	0	0	0	0
(14) = (11) + (12) + (13)	-43.63	-43.63	33.55	33.55	-24.59	-24.59	18.81	18.81
(15) Pressure	50.96	50.96	50.96	50.96	50.96	50.96	50.96	50.96
(16) = (14) + (15)	7.33	7.33	84.52	84.52	26.37	26.37	69.77	69.77
(17) Kb (Mϕ / P) . 6 P/ T^2	-4.83	4.83	-4.83	4.83	-11	11	-11	11
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-189.89	189.89	189.89	-189.89
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-37.21	37.21	37.21	-37.21	0	0	0	0
(20) = (17) + (18) + (19)	-42.05	42.05	32.38	-32.38	-200.89	200.89	178.89	-178.89
Shear stresses								
(21) Vc / Π ro T	0	0	0	0	0	0	0	0
(22) VL / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	-59.49	69.49	84.14	-3.78	-119.02	60.15	150.88	-10.24
σϕ = (16) + (20)	-34.72	49.38	116.9	52.14	-174.52	227.26	248.66	-109.11
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-34.72	69.49	116.9	52.14	-119.02	227.26	248.66	-10.24
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-59.49	49.38	84.14	-3.78	-174.52	60.15	150.88	-109.11
(26) = (24) – (25)	24.77	20.12	32.76	55.91	55.5	167.11	97.79	98.88
(27) = (6) – (16)	-2.33	-2.33	-44.33	-44.33	-55.81	-55.81	0.55	0.55

	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 248.66 MPa	404 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 84.52 MPa	202 MPa (1.5 f)

β = 0.226		Read values	Used values
Fig. 3C Fig. 3C	γ=100 γ=50	4.3588 3.6487	**(Pts A,B) Nx/P/Rm = 3.6591**
Fig. 4C Fig. 4C	γ=75 γ=50	8.3487 6.3201	**(Pts C,D) Nx/P/Rm = 6.3794**
Fig. 4C Fig. 4C	γ=75 γ=50	8.3487 6.3201	**(Pts A,B) Nϕ/P/Rm = 6.3794**
Fig. 3C Fig. 3C	γ=100 γ=50	4.3588 3.6487	**(Pts C,D) Nϕ/P/Rm = 3.6591**
Fig. 2C-1 Fig. 2C-1	γ=75 γ=50	0.0177 0.0242	**(Pts A,B) Mϕ/P = 0.024**
Fig. 1C Fig. 1C	γ=75 γ=50	*0.0446* *0.055*	**(Pts C,D) Mϕ/P = 0.0547**
Fig. 1C-1 Fig. 1C-1	γ=75 γ=50	0.0409 0.0513	**(Pts A,B) Mx/P = 0.051**
Fig. 2C Fig. 2C	γ=75 γ=50	*0.0161* *0.0226*	**(Pts C,D) Mx/P = 0.0224**
Fig. 3A Fig. 3A	γ=75 γ=50	2.5799 1.9355	**Nϕ/(Mc/Rm2 β) = 1.9543**
Fig. 4A Fig. 4A	γ=75 γ=50	6.9628 4.4171	**Nx/(Mc/Rm2 β) = 4.4915**
Fig. 1A Fig. 1A	γ=100 γ=50	0.0564 0.0673	**Mϕ/(Mc/Rm β) = 0.0671**
Fig. 2A Fig. 2A	γ=75 γ=50	0.0258 0.0302	**Mx/(Mc/Rm β) = 0.0301**
Fig. 3B Fig. 3B	γ=75 γ=50	5.614 4.4754	**Nϕ/(ML/Rm2 β) = 4.5087**
Fig. 4B Fig. 4B	γ=75 γ=50	2.8501 2.0311	**Nx/(ML/Rm2 β) = 2.055**
Fig. 1B Fig. 1B	γ=75 γ=50	0.0126 0.0172	**Mϕ/(ML/Rm β) = 0.0171**
Fig. 2B Fig. 2B	γ=75 γ=50	0.0167 0.0251	**Mx/(ML/Rm β) = 0.0249**

Opening reinforcement O2 int. pressure Tube Side Outlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                        P355NL1                   P355NL1
DESIGN PRESSURE P               0.5800 MPa
TEMPERATURE                     167.0  °C
CORROSION SHELL C /NOZZLE CT                          3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                  193.89 /     193.89 MPa
          PAD R                                                  193.89 MPa
JOINT EFFICIENCY V                                    1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT              1332.00 /     813.00 mm
THICKNESS SHELL E / NOZZLE ET                        16.00 /      16.00 mm
NOZZLE SCHEDULE
FLANGE RATING                   150.   lb
NOZZLE HEIGHT  H                539.00 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                149.35 mm
REINFORCEMENT WIDTH LR          234.00 mm
REINFORCEMENT THICKNESS ER       16.00 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in OPERATION            * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2*T+P).......................=      1.21 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ...................................=      0.00 mm
                 sA = E+h ...............................=     16.00 mm
                 sS = ET ................................=     16.00 mm
                 di = (DT-2*(ET-CT)) ....................=    787.00 mm
                 Di = D-2*(E-C)..........................=   1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    130.95 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=    127.48 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =....................................=    130.95 mm
                 lSr=....................................=     95.40 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = ..................................=     1702. mm²
                 As1 = ..................................=     1409. mm²
                 As2 = ..................................=     2095. mm²
                 Ap = ...................................=   393609. mm²
                 (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =  1008020. N
                                              >= P*Ap =   228293. N

                 h1 = ...................................=     16.00 mm
                 b1 = ...................................=    234.00 mm
                 b1.h1 >= b.h
```

Opening reinforcement O2 int. pressure Tube Side Outlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
DESIGN PRESSURE P               0.8717 MPa
TEMPERATURE                       20.0  °C
CORROSION SHELL C /NOZZLE CT                           3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                   328.57 /     328.57 MPa
          PAD R                                                   328.57 MPa
JOINT EFFICIENCY V                                     1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT               1332.00 /     813.00 mm
THICKNESS SHELL E / NOZZLE ET                         16.00 /      16.00 mm
NOZZLE SCHEDULE
FLANGE RATING                   150.   lb
NOZZLE HEIGHT  H                539.00 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                149.35 mm
REINFORCEMENT WIDTH LR          234.00 mm
REINFORCEMENT THICKNESS ER       16.00 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in TEST                 * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2*T+P)......................=      1.08 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ..................................=      0.00 mm
                 sA = E+h ..............................=     16.00 mm
                 sS = ET ...............................=     16.00 mm
                 di = (DT-2*(ET-CT)) ...................=    787.00 mm
                 Di = D-2*(E-C).........................=   1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    130.95 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=    127.48 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    130.95 mm
                 lSr=...................................=     95.40 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     1702. mm²
                 As1 = .................................=     1409. mm²
                 As2 = .................................=     2095. mm²
                 Ap = ..................................=   393609. mm²
                 P*[Ap/(As0+As1+As2)+1/2]               =     66.34 MPa
                                                   <= S =    328.57 MPa

                 h1 = ..................................=     16.00 mm
                 b1 = ..................................=    234.00 mm
                 b1.h1 >= b.h
```

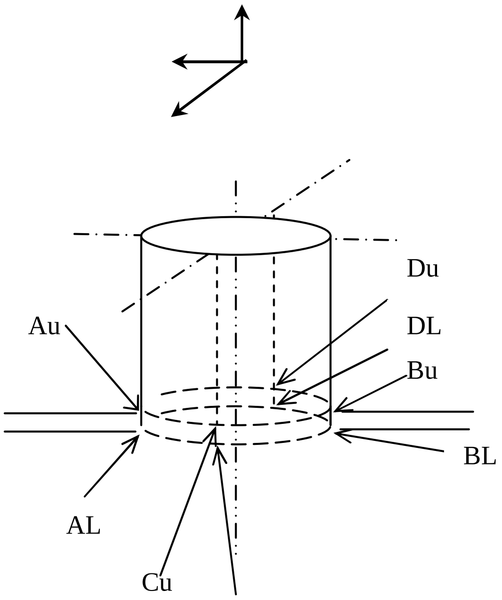
Opening reinforcement O2 ext. pressure Tube Side Outlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
EXT. PRESSURE                  0.1030 MPa
TEMPERATURE                    167.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 181.77 /     181.77 MPa
          PAD R                                                 181.77 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT             1332.00 /     813.00 mm
THICKNESS SHELL E / NOZZLE ET                       16.00 /      16.00 mm
NOZZLE SCHEDULE
FLANGE RATING                  150.   lb
NOZZLE HEIGHT  H               539.00 mm
NOZZLE INTERNAL HEIGHT M         0.00 mm
FLANGE HEIGHT EB               149.35 mm
REINFORCEMENT WIDTH LR         234.00 mm
REINFORCEMENT THICKNESS ER      16.00 mm
ECCENTRICITY                     0.00 mm
NOZZLE SLOPE ANGLE A             0.00 °

VESSEL in EXTERNAL PRESSURE    * CUT-OUT in SHELL

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =..................................=      2.21 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ..................................=      0.00 mm
                 sA = E+h ..............................=     16.00 mm
                 sS = ET ...............................=     16.00 mm
                 di = (DT-2*(ET-CT)) ...................=    787.00 mm
                 Di = D-2*(E-C).........................=   1306.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    130.95 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=    127.48 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    130.95 mm
                 lSr=...................................=     95.40 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     1702. mm²
                 As1 = .................................=     1409. mm²
                 As2 = .................................=     2095. mm²
                 Ap = ..................................=   393609. mm²
                 P*[Ap/(As0+As1+As2)+1/2]               =      7.84 MPa
                                                   <= S =    181.77 MPa

                 h1 = ..................................=     16.00 mm
                 b1 = ..................................=    234.00 mm
                 b1.h1 >= b.h
```

Local loads Tube Side Outlet O2, Loaded Area on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure		0.58 MPa
Existing circular stress		/
Existing longitudinal stress		/
Allowable stress		f=193.89 MPa
Yield strength		290.84 MPa
Modulus of Elasticity		191,640 MPa
Joint efficiency		1
Membrane stress factor		1.5
Design stress factor		3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Thickness Tr	16 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=406.5 mm

Geometric parameters

Mean radius Rm = (R + Tr) - [(Tr + Ts -c)/2] = 667.5 mm
Total thickness T = Tr + Ts - c = 29 mm
γ = Rm / T = 23.017
β = 0.875 ro / Rm = 0.533

Stress concentration factors

membrane Kn =1.782
bending Kb =1.482

Applied loads

Radial P = 10,630 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 100 daN.m
Bending moment ML = 13,000 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on Loaded Area

(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	7.97	7.97	7.97	7.97	19.22	19.22	19.22	19.22
(2) Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-0.63	-0.63	0.63	0.63
(3) Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-20.53	-20.53	20.53	20.53	0	0	0	0
(4) = (1) + (2) + (3)	-12.56	-12.56	28.5	28.5	18.59	18.59	19.85	19.85
(5) Pressure	14.78	14.78	14.78	14.78	14.78	14.78	14.78	14.78
(6) = (4) + (5)	2.21	2.21	43.28	43.28	33.37	33.37	34.63	34.63
(7) Kb (Mx / P) . 6 P/ T^2	20.82	-20.82	20.82	-20.82	5.3	-5.3	5.3	-5.3
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-0.84	0.84	0.84	-0.84
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-59.45	59.45	59.45	-59.45	0	0	0	0
(10) = (7) + (8) + (9)	-38.62	38.62	80.27	-80.27	4.46	-4.46	6.14	-6.14
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	19.22	19.22	19.22	19.22	7.97	7.97	7.97	7.97
(12) Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-0.17	-0.17	0.17	0.17
(13) Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-37.49	-37.49	37.49	37.49	0	0	0	0
(14) = (11) + (12) + (13)	-18.27	-18.27	56.71	56.71	7.79	7.79	8.14	8.14
(15) Pressure	29.56	29.56	29.56	29.56	29.56	29.56	29.56	29.56
(16) = (14) + (15)	11.29	11.29	86.27	86.27	37.35	37.35	37.7	37.7
(17) Kb (Mϕ / P) . 6 P/ T^2	9.14	-9.14	9.14	-9.14	18.83	-18.83	18.83	-18.83
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-1.88	1.88	1.88	-1.88
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-31.33	31.33	31.33	-31.33	0	0	0	0
(20) = (17) + (18) + (19)	-22.19	22.19	40.48	-40.48	16.95	-16.95	20.72	-20.72
Shear stresses								
(21) Vc / Π ro T	0	0	0	0	0	0	0	0
(22) VL / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	-36.41	40.84	123.55	-36.99	37.83	28.91	40.77	28.49
σϕ = (16) + (20)	-10.9	33.48	126.74	45.79	54.3	20.4	58.41	16.98
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2\ / 2$	-10.9	40.84	126.74	45.79	54.3	28.91	58.41	28.49
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2\ / 2$	-36.41	33.48	123.55	-36.99	37.83	20.4	40.77	16.98
(26) = (24) – (25)	25.51	7.36	3.19	82.79	16.48	8.51	17.65	11.51
(27) = (6) – (16)	-9.07	-9.07	-42.99	-42.99	-3.98	-3.98	-3.07	-3.07

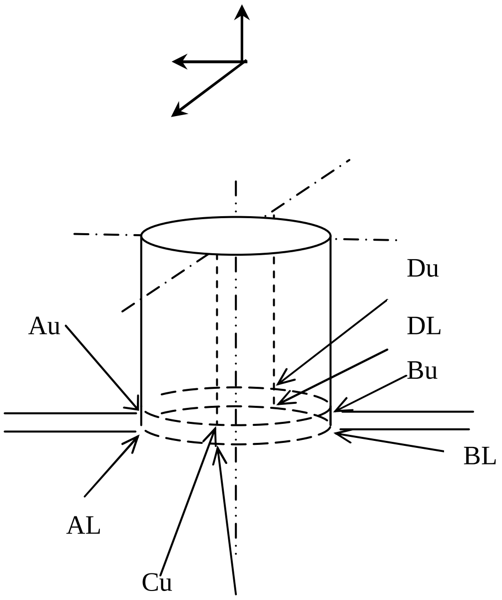
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 126.74 MPa	581.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 86.27 MPa	290.84 MPa (1.5 f)

β = 0.533		Read values	Used values
Fig. 3C Fig. 3C	γ=50 γ=15	*0.8971* *0.7894*	**(Pts A,B) Nx/P/Rm = 0.814**
Fig. 4C Fig. 4C	γ=25 γ=15	*2.0792* *1.4973*	**(Pts C,D) Nx/P/Rm = 1.9638**
Fig. 4C Fig. 4C	γ=25 γ=15	*2.0792* *1.4973*	**(Pts A,B) Nϕ/P/Rm = 1.9638**
Fig. 3C Fig. 3C	γ=50 γ=15	*0.8971* *0.7894*	**(Pts C,D) Nϕ/P/Rm = 0.814**
Fig. 2C-1 Fig. 2C-1	γ=25 γ=15	*0.0068* *0.0133*	**(Pts A,B) Mϕ/P = 0.0081**
Fig. 1C Fig. 1C	γ=25 γ=15	*0.0144* *0.0264*	**(Pts C,D) Mϕ/P = 0.0168**
Fig. 1C-1 Fig. 1C-1	γ=25 γ=15	*0.017* *0.0248*	**(Pts A,B) Mx/P = 0.0185**
Fig. 2C Fig. 2C	γ=25 γ=15	*0.0032* *0.0109*	**(Pts C,D) Mx/P = 0.0047**
Fig. 3A Fig. 3A	γ=25 γ=15	*0.6955* *0.5575*	**Nϕ/(Mc/Rm2 β) = 0.6681**
Fig. 4A Fig. 4A	γ=25 γ=15	*2.6285* *1.6285*	**Nx/(Mc/Rm2 β) = 2.4303**
Fig. 1A Fig. 1A	γ=50 γ=15	0.059 *0.0646*	**Mϕ/(Mc/Rm β) = 0.0633**
Fig. 2A Fig. 2A	γ=25 γ=15	*0.0277* *0.0308*	**Mx/(Mc/Rm β) = 0.0283**
Fig. 3B Fig. 3B	γ=25 γ=15	*1.1217* *1.083*	**Nϕ/(ML/Rm2 β) = 1.114**
Fig. 4B Fig. 4B	γ=25 γ=15	*0.6191* *0.574*	**Nx/(ML/Rm2 β) = 0.6101**
Fig. 1B Fig. 1B	γ=25 γ=15	*0.0076* *0.0102*	**Mϕ/(ML/Rm β) = 0.0081**
Fig. 2B Fig. 2B	γ=25 γ=15	*0.0141* *0.0206*	**Mx/(ML/Rm β) = 0.0154**

Local loads Tube Side Outlet O2, At the edge of reinforcing pad on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	0.58 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=193.89 MPa
Yield strength	290.84 MPa
Modulus of Elasticity	191,640 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Radius	640.5 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=640.5 mm

Geometric parameters

Mean radius Rm = R - [(Ts -c)/2] = 659.5 mm
Total thickness T = Ts - c = 13 mm
γ = Rm / T = 50.731
β = 0.875 ro / Rm = 0.85

Stress concentration factors

membrane Kn =1.48
bending Kb =1.23

Applied loads

Radial P = 10,630 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 100 daN.m
Bending moment ML = 13,000 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

(MPa)	Points							
	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	-1.35	-1.35	-1.35	-1.35	17.61	17.61	17.61	17.61
(2) Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-1.16	-1.16	1.16	1.16
(3) Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-7.27	-7.27	7.27	7.27	0	0	0	0
(4) = (1) + (2) + (3)	-8.63	-8.63	5.92	5.92	16.45	16.45	18.77	18.77
(5) Pressure	14.78	14.78	14.78	14.78	14.78	14.78	14.78	14.78
(6) = (4) + (5)	6.15	6.15	20.7	20.7	31.23	31.23	33.54	33.54
(7) Kb (Mx / P) . 6 P/ T^2	-30.81	30.81	-30.81	30.81	-21.66	21.66	-21.66	21.66
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-1.83	1.83	1.83	-1.83
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-3.65	3.65	3.65	-3.65	0	0	0	0
(10) = (7) + (8) + (9)	-34.45	34.45	-27.16	27.16	-23.49	23.49	-19.83	19.83
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	17.61	17.61	17.61	17.61	-1.35	-1.35	-1.35	-1.35
(12) Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-0.09	-0.09	0.09	0.09
(13) Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	0.32	0.32	-0.32	-0.32	0	0	0	0
(14) = (11) + (12) + (13)	17.93	17.93	17.29	17.29	-1.44	-1.44	-1.26	-1.26
(15) Pressure	29.56	29.56	29.56	29.56	29.56	29.56	29.56	29.56
(16) = (14) + (15)	47.49	47.49	46.85	46.85	28.11	28.11	28.3	28.3
(17) Kb (Mϕ / P) . 6 P/ T^2	-9.89	9.89	-9.89	9.89	-23.31	23.31	-23.31	23.31
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-4.59	4.59	4.59	-4.59
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	5.37	-5.37	-5.37	5.37	0	0	0	0
(20) = (17) + (18) + (19)	-4.53	4.53	-15.26	15.26	-27.9	27.9	-18.72	18.72
Shear stresses								
(21) Vc / Π ro T	0	0	0	0	0	0	0	0
(22) VL / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	-28.3	40.61	-6.46	47.86	7.74	54.72	13.71	53.38
σϕ = (16) + (20)	42.96	52.01	31.59	62.11	0.22	56.01	9.58	47.02
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	42.96	52.01	31.59	62.11	7.74	56.01	13.71	53.38
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-28.3	40.61	-6.46	47.86	0.22	54.72	9.58	47.02
(26) = (24) – (25)	71.26	11.41	38.04	14.24	7.52	1.29	4.13	6.36
(27) = (6) – (16)	-41.33	-41.33	-26.14	-26.14	3.12	3.12	5.24	5.24

	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 71.26 MPa	581.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 47.49 MPa	290.84 MPa (1.5 f)

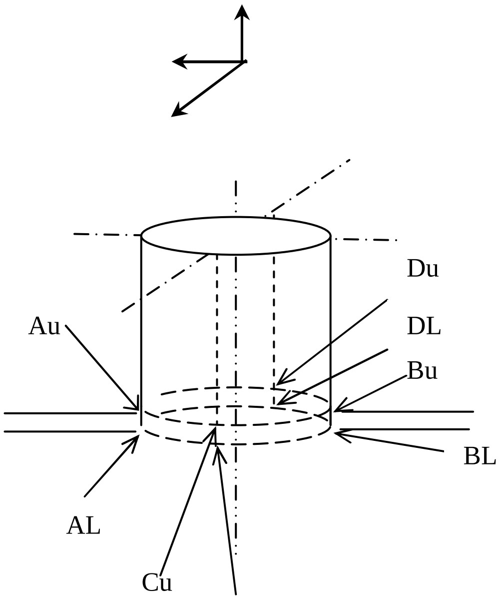
β = 0.85		Read values	Used values
Fig. 3C	γ=100	*0.1835*	
Fig. 3C	γ=50	*-0.0775*	
Fig. 4C	γ=75	*0.0762*	
Fig. 4C	γ=50	*0.9864*	**(Pts C,D) Nx/P/Rm = 0.9598**
Fig. 4C	γ=75	*0.0762*	
Fig. 4C	γ=50	*0.9864*	**(Pts A,B) Nϕ/P/Rm = 0.9598**
Fig. 3C	γ=100	*0.1835*	
Fig. 3C	γ=50	*-0.0775*	
Fig. 2C-1	γ=75	*-0.0017*	
Fig. 2C-1	γ=50	*-0.0021*	
Fig. 1C	γ=75	*-0.0053*	
Fig. 1C	γ=50	*-0.005*	
Fig. 1C-1	γ=75	*-0.0074*	
Fig. 1C-1	γ=50	*-0.0066*	
Fig. 2C	γ=75	*-0.003*	
Fig. 2C	γ=50	*-0.0047*	
Fig. 3A	γ=75	*0.3395*	
Fig. 3A	γ=50	*0.3019*	**Nϕ/(Mc/Rm2 β) = 0.303**
Fig. 4A	γ=75	*3.7985*	
Fig. 4A	γ=50	*3.7565*	**Nx/(Mc/Rm2 β) = 3.7577**
Fig. 1A	γ=100	0.053	
Fig. 1A	γ=50	0.059	**Mϕ/(Mc/Rm β) = 0.0589**
Fig. 2A	γ=75	0.022	
Fig. 2A	γ=50	0.0235	**Mx/(Mc/Rm β) = 0.0235**
Fig. 3B	γ=75	*-0.1545*	
Fig. 3B	γ=50	*-0.0036*	
Fig. 4B	γ=75	*-0.1884*	
Fig. 4B	γ=50	*0.1929*	**Nx/(ML/Rm2 β) = 0.1817**
Fig. 1B	γ=75	*-0.0006*	
Fig. 1B	γ=50	*-0.0005*	
Fig. 2B	γ=75	*0.0003*	
Fig. 2B	γ=50	*0.0004*	**Mx/(ML/Rm β) = 0.0004**

Local loads Tube Side Outlet O2, Loaded Area on cylindrical shell

WRC 107 Bulletin March 1979

Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Sign convention for loads and moments



Design pressure	0.58 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=193.89 MPa
Yield strength	290.84 MPa
Modulus of Elasticity	191,640 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Thickness Tr	16 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=406.5 mm

Geometric parameters

Mean radius Rm = (R + Tr) - [(Tr + Ts -c)/2] = 667.5 mm
Total thickness T = Tr + Ts - c = 29 mm
γ = Rm / T = 23.017
β = 0.875 ro / Rm = 0.533

Stress concentration factors

membrane Kn =1.782
bending Kb =1.482

Applied loads

Radial P = -10,630 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 100 daN.m
Bending moment ML = 13,000 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on Loaded Area

(MPa)		Points							
		Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses								
(1)	Kn (Nx / P / Rm) . P/ (RmT)	-7.97	-7.97	-7.97	-7.97	-19.22	-19.22	-19.22	-19.22
(2)	Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-0.63	-0.63	0.63	0.63
(3)	Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-20.53	-20.53	20.53	20.53	0	0	0	0
(4)	= (1) + (2) + (3)	-28.5	-28.5	12.56	12.56	-19.85	-19.85	-18.59	-18.59
(5)	Pressure	14.78	14.78	14.78	14.78	14.78	14.78	14.78	14.78
(6)	= (4) + (5)	-13.72	-13.72	27.34	27.34	-5.07	-5.07	-3.81	-3.81
(7)	Kb (Mx / P) . 6 P/ T^2	-20.82	20.82	-20.82	20.82	-5.3	5.3	-5.3	5.3
(8)	Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-0.84	0.84	0.84	-0.84
(9)	Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-59.45	59.45	59.45	-59.45	0	0	0	0
(10)	= (7) + (8) + (9)	-80.27	80.27	38.62	-38.62	-6.14	6.14	-4.46	4.46
	Circumferential stresses								
(11)	Kn (Nϕ / P / Rm) . P/ Rm / T	-19.22	-19.22	-19.22	-19.22	-7.97	-7.97	-7.97	-7.97
(12)	Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-0.17	-0.17	0.17	0.17
(13)	Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-37.49	-37.49	37.49	37.49	0	0	0	0
(14)	= (11) + (12) + (13)	-56.71	-56.71	18.27	18.27	-8.14	-8.14	-7.79	-7.79
(15)	Pressure	29.56	29.56	29.56	29.56	29.56	29.56	29.56	29.56
(16)	= (14) + (15)	-27.15	-27.15	47.83	47.83	21.42	21.42	21.76	21.76
(17)	Kb (Mϕ / P) . 6 P/ T^2	-9.14	9.14	-9.14	9.14	-18.83	18.83	-18.83	18.83
(18)	Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-1.88	1.88	1.88	-1.88
(19)	Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-31.33	31.33	31.33	-31.33	0	0	0	0
(20)	= (17) + (18) + (19)	-40.48	40.48	22.19	-22.19	-20.72	20.72	-16.95	16.95
	Shear stresses								
(21)	Vc / Π ro T	0	0	0	0	0	0	0	0
(22)	VL / Π ro T	0	0	0	0	0	0	0	0
(23)	Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
	σx = (6) + (10)	-93.99	66.55	65.97	-11.28	-11.21	1.07	-8.27	0.64
	σϕ = (16) + (20)	-67.63	13.32	70.02	25.64	0.7	42.13	4.81	38.72
	τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24)	$(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-67.63	66.55	70.02	25.64	0.7	42.13	4.81	38.72
(25)	$(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-93.99	13.32	65.97	-11.28	-11.21	1.07	-8.27	0.64
(26)	= (24) – (25)	26.37	53.23	4.05	36.92	11.91	41.07	13.08	38.07
(27)	= (6) – (16)	13.43	13.43	-20.48	-20.48	-26.49	-26.49	-25.58	-25.58

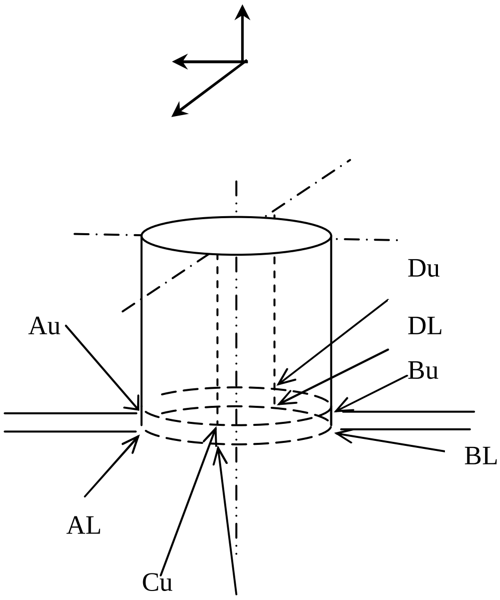
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 93.99 MPa	581.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 47.83 MPa	290.84 MPa (1.5 f)

β = 0.533		Read values	Used values
Fig. 3C Fig. 3C	γ=50 γ=15	*0.8971* *0.7894*	**(Pts A,B) Nx/P/Rm = 0.814**
Fig. 4C Fig. 4C	γ=25 γ=15	*2.0792* *1.4973*	**(Pts C,D) Nx/P/Rm = 1.9638**
Fig. 4C Fig. 4C	γ=25 γ=15	*2.0792* *1.4973*	**(Pts A,B) Nϕ/P/Rm = 1.9638**
Fig. 3C Fig. 3C	γ=50 γ=15	*0.8971* *0.7894*	**(Pts C,D) Nϕ/P/Rm = 0.814**
Fig. 2C-1 Fig. 2C-1	γ=25 γ=15	*0.0068* *0.0133*	**(Pts A,B) Mϕ/P = 0.0081**
Fig. 1C Fig. 1C	γ=25 γ=15	*0.0144* *0.0264*	**(Pts C,D) Mϕ/P = 0.0168**
Fig. 1C-1 Fig. 1C-1	γ=25 γ=15	*0.017* *0.0248*	**(Pts A,B) Mx/P = 0.0185**
Fig. 2C Fig. 2C	γ=25 γ=15	*0.0032* *0.0109*	**(Pts C,D) Mx/P = 0.0047**
Fig. 3A Fig. 3A	γ=25 γ=15	*0.6955* *0.5575*	**Nϕ/(Mc/Rm2 β) = 0.6681**
Fig. 4A Fig. 4A	γ=25 γ=15	*2.6285* *1.6285*	**Nx/(Mc/Rm2 β) = 2.4303**
Fig. 1A Fig. 1A	γ=50 γ=15	0.059 *0.0646*	**Mϕ/(Mc/Rm β) = 0.0633**
Fig. 2A Fig. 2A	γ=25 γ=15	*0.0277* *0.0308*	**Mx/(Mc/Rm β) = 0.0283**
Fig. 3B Fig. 3B	γ=25 γ=15	*1.1217* *1.083*	**Nϕ/(ML/Rm2 β) = 1.114**
Fig. 4B Fig. 4B	γ=25 γ=15	*0.6191* *0.574*	**Nx/(ML/Rm2 β) = 0.6101**
Fig. 1B Fig. 1B	γ=25 γ=15	*0.0076* *0.0102*	**Mϕ/(ML/Rm β) = 0.0081**
Fig. 2B Fig. 2B	γ=25 γ=15	*0.0141* *0.0206*	**Mx/(ML/Rm β) = 0.0154**

Local loads Tube Side Outlet O2, At the edge of reinforcing pad on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	0.58 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=193.89 MPa
Yield strength	290.84 MPa
Modulus of Elasticity	191,640 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Radius 640.5 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=640.5 mm

Geometric parameters

Mean radius Rm = R - [(Ts -c)/2] = 659.5 mm
Total thickness T = Ts - c = 13 mm
γ = Rm / T = 50.731
β = 0.875 ro / Rm = 0.85

Stress concentration factors

membrane Kn =1.48
bending Kb =1.23

Applied loads

Radial P = -10,630 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 100 daN.m
Bending moment ML = 13,000 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

		Points							
	(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses								
(1)	Kn (Nx / P / Rm) . P/ (RmT)	1.35	1.35	1.35	1.35	-17.61	-17.61	-17.61	-17.61
(2)	Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-1.16	-1.16	1.16	1.16
(3)	Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-7.27	-7.27	7.27	7.27	0	0	0	0
(4)	= (1) + (2) + (3)	-5.92	-5.92	8.63	8.63	-18.77	-18.77	-16.45	-16.45
(5)	Pressure	14.78	14.78	14.78	14.78	14.78	14.78	14.78	14.78
(6)	= (4) + (5)	8.86	8.86	23.41	23.41	-3.99	-3.99	-1.67	-1.67
(7)	Kb (Mx / P) . 6 P/ T^2	30.81	-30.81	30.81	-30.81	21.66	-21.66	21.66	-21.66
(8)	Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-1.83	1.83	1.83	-1.83
(9)	Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-3.65	3.65	3.65	-3.65	0	0	0	0
(10)	= (7) + (8) + (9)	27.16	-27.16	34.45	-34.45	19.83	-19.83	23.49	-23.49
	Circumferential stresses								
(11)	Kn (Nϕ / P / Rm) . P/ Rm / T	-17.61	-17.61	-17.61	-17.61	1.35	1.35	1.35	1.35
(12)	Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	-0.09	-0.09	0.09	0.09
(13)	Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	0.32	0.32	-0.32	-0.32	0	0	0	0
(14)	= (11) + (12) + (13)	-17.29	-17.29	-17.93	-17.93	1.26	1.26	1.44	1.44
(15)	Pressure	29.56	29.56	29.56	29.56	29.56	29.56	29.56	29.56
(16)	= (14) + (15)	12.27	12.27	11.63	11.63	30.82	30.82	31	31
(17)	Kb (Mϕ / P) . 6 P/ T^2	9.89	-9.89	9.89	-9.89	23.31	-23.31	23.31	-23.31
(18)	Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	-4.59	4.59	4.59	-4.59
(19)	Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	5.37	-5.37	-5.37	5.37	0	0	0	0
(20)	= (17) + (18) + (19)	15.26	-15.26	4.53	-4.53	18.72	-18.72	27.9	-27.9
	Shear stresses								
(21)	Vc / Π ro T	0	0	0	0	0	0	0	0
(22)	VL / Π ro T	0	0	0	0	0	0	0	0
(23)	Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
	σx = (6) + (10)	36.01	-18.3	57.86	-11.05	15.85	-23.82	21.81	-25.16
	σϕ = (16) + (20)	27.53	-2.99	16.16	7.1	49.53	12.1	58.9	3.11
	τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24)	$(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	36.01	-2.99	57.86	7.1	49.53	12.1	58.9	3.11
(25)	$(\sigma\phi + \sigma x\ - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	27.53	-18.3	16.16	-11.05	15.85	-23.82	21.81	-25.16
(26)	= (24) – (25)	8.49	15.31	41.7	18.15	33.69	35.92	37.08	28.27
(27)	= (6) – (16)	-3.41	-3.41	11.78	11.78	-34.8	-34.8	-32.67	-32.67

	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 58.9 MPa	581.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 31 MPa	290.84 MPa (1.5 f)

***β* = 0.85**		Read values	Used values
Fig. 3C	γ=100	*0.1835*	
Fig. 3C	γ=50	*-0.0775*	
Fig. 4C	γ=75	*0.0762*	
Fig. 4C	γ=50	*0.9864*	**(Pts C,D) Nx/P/Rm = 0.9598**
Fig. 4C	γ=75	*0.0762*	
Fig. 4C	γ=50	*0.9864*	**(Pts A,B) Nϕ/P/Rm = 0.9598**
Fig. 3C	γ=100	*0.1835*	
Fig. 3C	γ=50	*-0.0775*	
Fig. 2C-1	γ=75	*-0.0017*	
Fig. 2C-1	γ=50	*-0.0021*	
Fig. 1C	γ=75	*-0.0053*	
Fig. 1C	γ=50	*-0.005*	
Fig. 1C-1	γ=75	*-0.0074*	
Fig. 1C-1	γ=50	*-0.0066*	
Fig. 2C	γ=75	*-0.003*	
Fig. 2C	γ=50	*-0.0047*	
Fig. 3A	γ=75	*0.3395*	
Fig. 3A	γ=50	*0.3019*	**Nϕ/(Mc/Rm2 β) = 0.303**
Fig. 4A	γ=75	*3.7985*	
Fig. 4A	γ=50	*3.7565*	**Nx/(Mc/Rm2 β) = 3.7577**
Fig. 1A	γ=100	0.053	
Fig. 1A	γ=50	0.059	**Mϕ/(Mc/Rm β) = 0.0589**
Fig. 2A	γ=75	0.022	
Fig. 2A	γ=50	0.0235	**Mx/(Mc/Rm β) = 0.0235**
Fig. 3B	γ=75	*-0.1545*	
Fig. 3B	γ=50	*-0.0036*	
Fig. 4B	γ=75	*-0.1884*	
Fig. 4B	γ=50	*0.1929*	**Nx/(ML/Rm2 β) = 0.1817**
Fig. 1B	γ=75	*-0.0006*	
Fig. 1B	γ=50	*-0.0005*	
Fig. 2B	γ=75	*0.0003*	
Fig. 2B	γ=50	*0.0004*	**Mx/(ML/Rm β) = 0.0004**

Opening reinforcement I2 int. pressure Tube Side Inlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                         P355NL1                  P355NL1
DESIGN PRESSURE P              0.5800 MPa
TEMPERATURE                    167.0  °C
CORROSION SHELL C /NOZZLE CT                          3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                  188.56 /     182.76 MPa
          PAD R                                                  188.56 MPa
JOINT EFFICIENCY V                                    1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT              1340.00 /     610.00 mm
THICKNESS SHELL E / NOZZLE ET                        20.00 /      14.00 mm
NOZZLE SCHEDULE
FLANGE RATING                  150.   lb
NOZZLE HEIGHT  H               163.31 mm
NOZZLE INTERNAL HEIGHT M         0.00 mm
FLANGE HEIGHT EB               152.40 mm
REINFORCEMENT WIDTH LR          95.00 mm
REINFORCEMENT THICKNESS ER      20.00 mm
ECCENTRICITY                     0.00 mm
NOZZLE SLOPE ANGLE A             0.00 °

VESSEL in OPERATION            * BRANCH CONNECTION ON KORBOGGEN HEAD

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2*T+P).......................=      0.97 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ...................................=      0.00 mm
                 sA = E+h ...............................=     20.00 mm
                 sS = ET ................................=     14.00 mm
                 di = (DT-2*(ET-CT)) ....................=    588.00 mm
                 Di = 2*(0.8*D+C)........................=   2150.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    191.93 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
                 lS = 1.SQRT((di+sS-CT)*(sS-CT)) ........=     81.17 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =....................................=    191.93 mm
                 lSr=....................................=     81.17 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = ..................................=     3263. mm²
                 As1 = ..................................=     1080. mm²
                 As2 = ..................................=     1900. mm²
                 Ap = ...................................=   293870. mm²
                 (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =  1169067. N
                                             >= P*Ap =   170445. N

                 h1 = ...................................=     20.00 mm
                 b1 = ...................................=     95.00 mm
                 b1.h1 >= b.h
```

Opening reinforcement I2 int. pressure Tube Side Inlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
DESIGN PRESSURE P               0.8717 MPa
TEMPERATURE                      20.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 319.05 /     338.10 MPa
          PAD R                                                 319.05 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT             1340.00 /     610.00 mm
THICKNESS SHELL E / NOZZLE ET                       20.00 /      14.00 mm
NOZZLE SCHEDULE
FLANGE RATING                   150.   lb
NOZZLE HEIGHT  H                163.31 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                152.40 mm
REINFORCEMENT WIDTH LR           95.00 mm
REINFORCEMENT THICKNESS ER       20.00 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in TEST                 * BRANCH CONNECTION ON KORBOGGEN HEAD

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2*T+P).......................=      0.79 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ...................................=      0.00 mm
                 sA = E+h ...............................=     20.00 mm
                 sS = ET ................................=     14.00 mm
                 di = (DT-2*(ET-CT)) ....................=    588.00 mm
                 Di = 2*(0.8*D+C)........................=   2150.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    191.93 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
                 lS = 1.SQRT((di+sS-CT)*(sS-CT)) ........=     81.17 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =....................................=    191.93 mm
                 lSr=....................................=     81.17 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = ..................................=     3263. mm2
                 As1 = ..................................=     1080. mm2
                 As2 = ..................................=     1900. mm2
                 Ap = ...................................=   293870. mm2
                 P*[Ap/(As0+As1+As2)+1/2]                =     41.47 MPa
                                                   <= S =    319.05 MPa

                 h1 = ...................................=     20.00 mm
                 b1 = ...................................=     95.00 mm
                 b1.h1 >= b.h
```

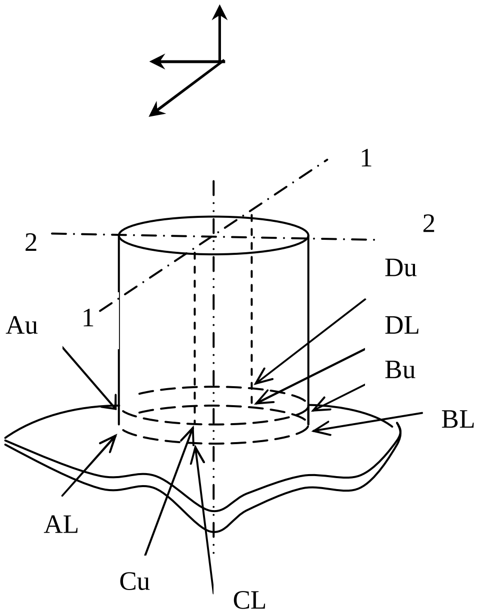
Opening reinforcement I2 ext. pressure Tube Side Inlet

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
EXT. PRESSURE                   0.1030 MPa
TEMPERATURE                     167.0  °C
CORROSION SHELL C /NOZZLE CT                           3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                   188.56 /     171.34 MPa
          PAD R                                                   176.77 MPa
JOINT EFFICIENCY V                                     1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT               1340.00 /     610.00 mm
THICKNESS SHELL E / NOZZLE ET                         20.00 /      14.00 mm
NOZZLE SCHEDULE
FLANGE RATING                   150.   lb
NOZZLE HEIGHT  H                163.31 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                152.40 mm
REINFORCEMENT WIDTH LR           95.00 mm
REINFORCEMENT THICKNESS ER       20.00 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in EXTERNAL PRESSURE    * BRANCH CONNECTION ON KORBOGGEN HEAD

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =..................................=      1.13 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 h  = ..................................=      0.00 mm
                 sA = E+h ..............................=     20.00 mm
                 sS = ET ...............................=     14.00 mm
                 di = (DT-2*(ET-CT)) ...................=    588.00 mm
                 Di = 2*(0.8*D+C).......................=   2150.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    191.93 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
                 lS = 1.SQRT((di+sS-CT)*(sS-CT)) ........=     81.17 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    191.93 mm
                 lSr=...................................=     81.17 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     3263. mm2
                 As1 = .................................=     1080. mm2
                 As2 = .................................=     1900. mm2
                 Ap = ..................................=   293870. mm2
                 (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =  1135830. N
                                                >= P*Ap =    30269. N

                 h1 = ..................................=     20.00 mm
                 b1 = ..................................=     95.00 mm
                 b1.h1 >= b.h
```

Local loads Tube Side Inlet I2, Loaded Area on spherical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code :	AD-MERKBLAETTER 2000 (11-2007)

Design pressure	0.58 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=188.56 MPa
Yield strength	282.84 MPa
Modulus of Elasticity	191,640 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=1,092 mm
Thickness	Ts=20 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Thickness Tr	20 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=305 mm

Geometric parameters

Mean radius $Rm = (R + Tr) - [(Tr + Ts - c)/2] = 1{,}093.5$ mm
Total thickness $T = Tr + Ts - c = 37$ mm
$U = ro / \sqrt{Rm\, T} = 1.516$

Stress concentration factors

membrane Kn =1.932
bending Kb =1.605

Applied loads

Radial load P = 12,760 daN
Load V_1 = 0 daN
load V_2 = 0 daN
Moment M_1 = 0 daN.m
Moment M_2 = 18,200 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on Loaded Area

(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
(1) Kn (Ny T / P) . P/ T^2	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
(2) Kn (Ny T $\sqrt{RmT}$ / M_2)	-14.66	-14.66	14.66	14.66	0	0	0	0
(3) Kn (Ny T $\sqrt{RmT}$ / M_1)	0	0	0	0	0	0	0	0
(4) = (1) + (2) + (3)	-12.63	-12.63	16.68	16.68	2.02	2.02	2.02	2.02
(5) Pressure	18.19	18.19	18.19	18.19	18.19	18.19	18.19	18.19
(6) = (4) + (5)	5.56	5.56	34.87	34.87	20.22	20.22	20.22	20.22
(7) Kb (My / P) . 6 P/ T^2	4.87	-4.87	4.87	-4.87	4.87	-4.87	4.87	-4.87
(8) Kb (My $\sqrt{RmT}$ / M_2) . 6M_2/ (T^2 $\sqrt{RmT}$)	-52.86	52.86	52.86	-52.86	0	0	0	0
(9) Kb (My $\sqrt{RmT}$ / M_1) . 6M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(10) = (7) + (8) +(9)	-48	48	57.73	-57.73	4.87	-4.87	4.87	-4.87
(11) Kn (Nx T / P) . P/ T^2	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58
(12) Kn (Nx T $\sqrt{RmT}$ / M_2) . M_2/ (T^2 $\sqrt{RmT}$)	-50.01	-50.01	50.01	50.01	0	0	0	0
(13) Kn (Nx T $\sqrt{RmT}$ / M_1) . M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(14) = (11) + (12) + (13)	-43.43	-43.43	56.58	56.58	6.58	6.58	6.58	6.58
(15) Pressure	18.19	18.19	18.19	18.19	18.19	18.19	18.19	18.19
(16) = (14) + (15)	-25.24	-25.24	74.78	74.78	24.77	24.77	24.77	24.77
(17) Kb (Mx / P) . 6 P/ T^2	15.91	-15.91	15.91	-15.91	15.91	-15.91	15.91	-15.91
(18) Kb (Mx $\sqrt{RmT}$ / M_2) . 6M_2/ (T^2 $\sqrt{RmT}$)	-174.75	174.75	174.75	-174.75	0	0	0	0
(19) Kb (Mx $\sqrt{RmT}$ / M_1) . 6M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(20) (17) + (18) + (19)	-158.84	158.84	190.67	-190.67	15.91	-15.91	15.91	-15.91
Shear stresses								
(21) v1 / Π ro T	0	0	0	0	0	0	0	0
(22) v2 / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (16) + (20)	-184.08	133.6	265.44	-115.89	40.68	8.86	40.68	8.86
σy = (6) + (10)	-42.44	53.56	92.61	-22.86	25.09	15.35	25.09	15.35
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma y + \sigma x + \sqrt{((\sigma y - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-42.44	133.6	265.44	-22.86	40.68	15.35	40.68	15.35
(25) $(\sigma y + \sigma x - \sqrt{((\sigma y - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	-184.08	53.56	92.61	-115.89	25.09	8.86	25.09	8.86
(26) = (24) – (25)	141.64	80.04	172.84	93.03	15.6	6.49	15.6	6.49
(27) = (6) – (16)	30.8	30.8	-39.9	-39.9	-4.55	-4.55	-4.55	-4.55

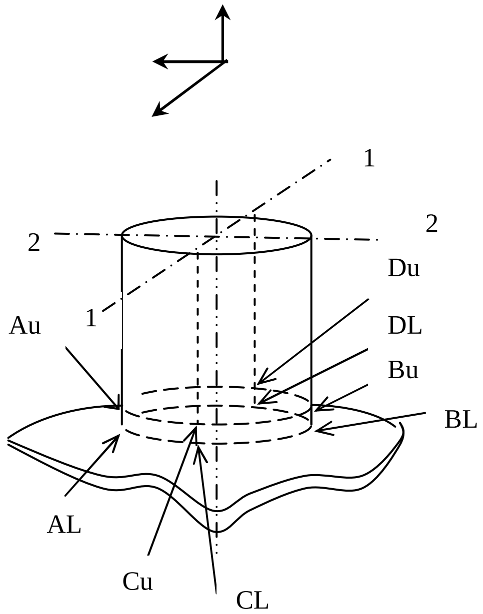
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 265.44 MPa	565.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 74.78 MPa	282.84 MPa (1.5 f)

U = 1.516	Read values	Used values
Fig.SR-2	0.0365	**NiT/P (Nx) = 0.0365**
Fig.SR-2	0.0177	**Mi/P (Mx) = 0.0177**
Fig.SR-2	0.0112	**NiT/P (Ny) = 0.0112**
Fig.SR-2	0.0054	**Mi/P (My) = 0.0054**
Fig.SR-3	0.0392	**NiT(Rm/T)1/2 / M cosθ = 0.0392**
Fig.SR-3	0.0275	**Mi(Rm/T)1/2 / M cosθ = 0.0275**
Fig.SR-3	0.0115	**NiT(Rm/T)1/2 / M cosθ = 0.0115**
Fig.SR-3	0.0083	**Mi(Rm/T)1/2 / M cosθ = 0.0083**

Local loads Tube Side Inlet I2, At the edge of reinforcing pad on spherical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	0.58 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=188.56 MPa
Yield strength	282.84 MPa
Modulus of Elasticity	191,640 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=1,092 mm
Thickness	Ts=20 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Radius	400 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=400 mm

Geometric parameters

Mean radius Rm = R - [(Ts -c)/2] = 1,083.5 mm
Total thickness T = Ts - c = 17 mm
$U = ro / \sqrt{Rm\ T} = 2.947$

Stress concentration factors

membrane Kn =1.589
bending Kb =1.319

Applied loads

Radial load P = 12,760 daN
Load V_1 = 0 daN
load V_2 = 0 daN
Moment M_1 = 0 daN.m
Moment M_2 = 18,200 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

	Points							
(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
(1) Kn (Ny T / P) . P/ T^2	3.22	3.22	3.22	3.22	3.22	3.22	3.22	3.22
(2) Kn (Ny T $\sqrt{RmT}$ / M_2)	-18.7	-18.7	18.7	18.7	0	0	0	0
(3) Kn (Ny T $\sqrt{RmT}$ / M_1)	0	0	0	0	0	0	0	0
(4) = (1) + (2) + (3)	-15.47	-15.47	21.92	21.92	3.22	3.22	3.22	3.22
(5) Pressure	18.19	18.19	18.19	18.19	18.19	18.19	18.19	18.19
(6) = (4) + (5)	2.72	2.72	40.11	40.11	21.42	21.42	21.42	21.42
(7) Kb (My / P) . 6 P/ T^2	7.16	-7.16	7.16	-7.16	7.16	-7.16	7.16	-7.16
(8) Kb (My $\sqrt{RmT}$ / M_2) . 6M_2/ (T^2 $\sqrt{RmT}$)	-51.32	51.32	51.32	-51.32	0	0	0	0
(9) Kb (My $\sqrt{RmT}$ / M_1) . 6M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(10) = (7) + (8) +(9)	-44.16	44.16	58.48	-58.48	7.16	-7.16	7.16	-7.16
(11) Kn (Nx T / P) . P/ T^2	9.11	9.11	9.11	9.11	9.11	9.11	9.11	9.11
(12) Kn (Nx T $\sqrt{RmT}$ / M_2) . M_2/ (T^2 $\sqrt{RmT}$)	-52.58	-52.58	52.58	52.58	0	0	0	0
(13) Kn (Nx T $\sqrt{RmT}$ / M_1) . M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(14) = (11) + (12) + (13)	-43.47	-43.47	61.69	61.69	9.11	9.11	9.11	9.11
(15) Pressure	18.19	18.19	18.19	18.19	18.19	18.19	18.19	18.19
(16) = (14) + (15)	-25.27	-25.27	79.88	79.88	27.3	27.3	27.3	27.3
(17) Kb (Mx / P) . 6 P/ T^2	20.07	-20.07	20.07	-20.07	20.07	-20.07	20.07	-20.07
(18) Kb (Mx $\sqrt{RmT}$ / M_2) . 6M_2/ (T^2 $\sqrt{RmT}$)	-185.96	185.96	185.96	-185.96	0	0	0	0
(19) Kb (Mx $\sqrt{RmT}$ / M_1) . 6M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(20) (17) + (18) + (19)	-165.88	165.88	206.03	-206.03	20.07	-20.07	20.07	-20.07
Shear stresses								
(21) v1 / Π ro T	0	0	0	0	0	0	0	0
(22) v2 / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (16) + (20)	-191.16	140.61	285.91	-126.15	47.38	7.23	47.38	7.23
σy = (6) + (10)	-41.44	46.89	98.6	-18.37	28.58	14.26	28.58	14.26
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma y + \sigma x + \sqrt{((\sigma y - \sigma x)^2 + 4\tau^2})^2 / 2$	-41.44	140.61	285.91	-18.37	47.38	14.26	47.38	14.26
(25) $(\sigma y + \sigma x - \sqrt{((\sigma y - \sigma x)^2 + 4\tau^2})^2 / 2$	-191.16	46.89	98.6	-126.15	28.58	7.23	28.58	7.23
(26) = (24) – (25)	149.72	93.73	187.31	107.78	18.8	7.03	18.8	7.03
(27) = (6) – (16)	28	28	-39.76	-39.76	-5.88	-5.88	-5.88	-5.88

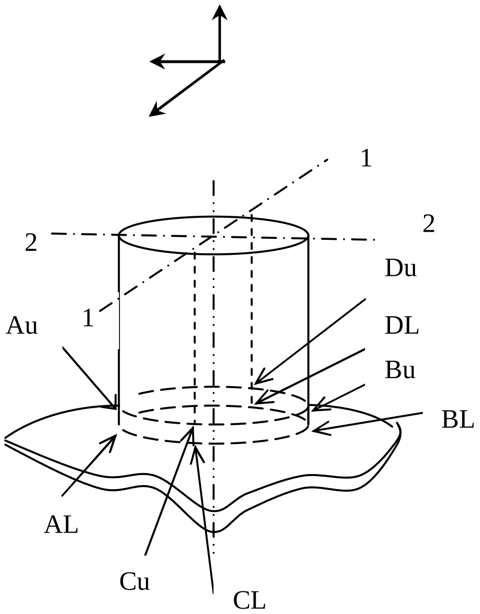
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 285.91 MPa	565.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 79.88 MPa	282.84 MPa (1.5 f)

U = 2.947	Read values	Used values
Fig.SR-2	*0.013*	**NiT/P (Nx) = 0.013**
Fig.SR-2	*0.0057*	**Mi/P (Mx) = 0.0057**
Fig.SR-2	*0.0046*	**NiT/P (Ny) = 0.0046**
Fig.SR-2	*0.002*	**Mi/P (My) = 0.002**
Fig.SR-3	*0.0071*	**NiT(Rm/T)1/2 / M cosθ = 0.0071**
Fig.SR-3	*0.0051*	**Mi(Rm/T)1/2 / M cosθ = 0.0051**
Fig.SR-3	*0.0025*	**NiT(Rm/T)1/2 / M cosθ = 0.0025**
Fig.SR-3	*0.0014*	**Mi(Rm/T)1/2 / M cosθ = 0.0014**

Local loads Tube Side Inlet I2, Loaded Area on spherical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code :	AD-MERKBLAETTER 2000 (11-2007)	
Design pressure		0.58 MPa
Existing circular stress		/
Existing longitudinal stress		/
Allowable stress		f=188.56 MPa
Yield strength		282.84 MPa
Modulus of Elasticity		191,640 MPa
Joint efficiency		1
Membrane stress factor		1.5
Design stress factor		3

Shell dimensions

External radius R=1,092 mm
Thickness Ts=20 mm
Corrosion allowance c=3 mm

Reinforcing pad dimensions

Thickness Tr 20 mm

Dimensions of Loaded Area

Fillet radius 15.21 mm
External radius ro=305 mm

Geometric parameters

Mean radius Rm = (R + Tr) - [(Tr + Ts -c)/2] = 1,093.5 mm
Total thickness T = Tr + Ts - c = 37 mm

$U = ro / \sqrt{Rm\ T} = 1.516$

Stress concentration factors

membrane Kn =1.932
bending Kb =1.605

Applied loads

Radial load P = -12,760 daN
Load V_1 = 0 daN
load V_2 = 0 daN
Moment M_1 = 0 daN.m
Moment M_2 = 18,200 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on Loaded Area

		Points							
	(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
(1)	Kn (Ny T / P) . P/ T^2	-2.02	-2.02	-2.02	-2.02	-2.02	-2.02	-2.02	-2.02
(2)	Kn (Ny T $\sqrt{RmT}$ / M_2)	-14.66	-14.66	14.66	14.66	0	0	0	0
(3)	Kn (Ny T $\sqrt{RmT}$ / M_1)	0	0	0	0	0	0	0	0
(4)	= (1) + (2) + (3)	-16.68	-16.68	12.63	12.63	-2.02	-2.02	-2.02	-2.02
(5)	Pressure	18.19	18.19	18.19	18.19	18.19	18.19	18.19	18.19
(6)	= (4) + (5)	1.51	1.51	30.83	30.83	16.17	16.17	16.17	16.17
(7)	Kb (My / P) . 6 P/ T^2	-4.87	4.87	-4.87	4.87	-4.87	4.87	-4.87	4.87
(8)	Kb (My $\sqrt{RmT}$ / M_2) . $6M_2$/ (T^2 $\sqrt{RmT}$)	-52.86	52.86	52.86	-52.86	0	0	0	0
(9)	Kb (My $\sqrt{RmT}$ / M_1) . $6M_1$/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(10)	= (7) + (8) +(9)	-57.73	57.73	48	-48	-4.87	4.87	-4.87	4.87
(11)	Kn (Nx T / P) . P/ T^2	-6.58	-6.58	-6.58	-6.58	-6.58	-6.58	-6.58	-6.58
(12)	Kn (Nx T $\sqrt{RmT}$ / M_2) . M_2/ (T^2 $\sqrt{RmT}$)	-50.01	-50.01	50.01	50.01	0	0	0	0
(13)	Kn (Nx T $\sqrt{RmT}$ / M_1) . M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(14)	= (11) + (12) + (13)	-56.58	-56.58	43.43	43.43	-6.58	-6.58	-6.58	-6.58
(15)	Pressure	18.19	18.19	18.19	18.19	18.19	18.19	18.19	18.19
(16)	= (14) + (15)	-38.39	-38.39	61.62	61.62	11.62	11.62	11.62	11.62
(17)	Kb (Mx / P) . 6 P/ T^2	-15.91	15.91	-15.91	15.91	-15.91	15.91	-15.91	15.91
(18)	Kb (Mx $\sqrt{RmT}$ / M_2) . $6M_2$/ (T^2 $\sqrt{RmT}$)	-174.75	174.75	174.75	-174.75	0	0	0	0
(19)	Kb (Mx $\sqrt{RmT}$ / M_1) . $6M_1$/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(20)	(17) + (18) + (19)	-190.67	190.67	158.84	-158.84	-15.91	15.91	-15.91	15.91
	Shear stresses								
(21)	v1 / Π ro T	0	0	0	0	0	0	0	0
(22)	v2 / Π ro T	0	0	0	0	0	0	0	0
(23)	Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
	σx = (16) + (20)	-229.06	152.28	220.46	-97.22	-4.3	27.53	-4.3	27.53
	σy = (6) + (10)	-56.22	59.24	78.82	-17.17	11.3	21.04	11.3	21.04
	τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24)	$(\sigma y + \sigma x + \sqrt{((\sigma y - \sigma x)^2 + 4\tau^2})^2 \ / \ 2$	-56.22	152.28	220.46	-17.17	11.3	27.53	11.3	27.53
(25)	$(\sigma y + \sigma x - \sqrt{((\sigma y - \sigma x)^2 + 4\tau^2})^2 \ / \ 2$	-229.06	59.24	78.82	-97.22	-4.3	21.04	-4.3	21.04
(26)	= (24) – (25)	172.84	93.03	141.64	80.04	15.6	6.49	15.6	6.49
(27)	= (6) – (16)	39.9	39.9	-30.8	-30.8	4.55	4.55	4.55	4.55

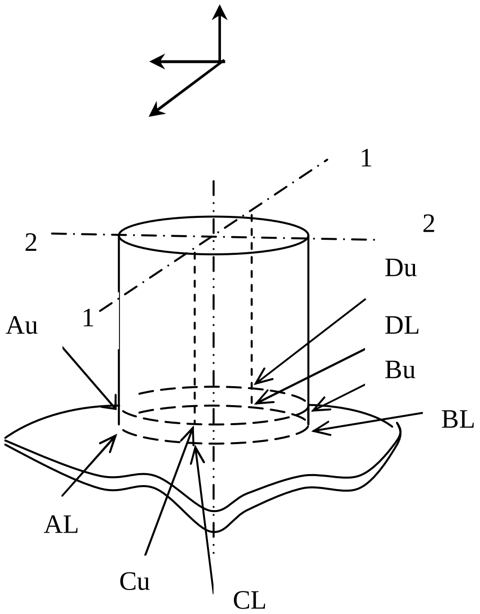
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 229.06 MPa	565.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 61.62 MPa	282.84 MPa (1.5 f)

U = 1.516	Read values	Used values
Fig.SR-2	0.0365	**NiT/P (Nx) = 0.0365**
Fig.SR-2	0.0177	**Mi/P (Mx) = 0.0177**
Fig.SR-2	0.0112	**NiT/P (Ny) = 0.0112**
Fig.SR-2	0.0054	**Mi/P (My) = 0.0054**
Fig.SR-3	0.0392	**NiT(Rm/T)1/2 / M cosθ = 0.0392**
Fig.SR-3	0.0275	**Mi(Rm/T)1/2 / M cosθ = 0.0275**
Fig.SR-3	0.0115	**NiT(Rm/T)1/2 / M cosθ = 0.0115**
Fig.SR-3	0.0083	**Mi(Rm/T)1/2 / M cosθ = 0.0083**

Local loads Tube Side Inlet I2, At the edge of reinforcing pad on spherical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	0.58 MPa
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=188.56 MPa
Yield strength	282.84 MPa
Modulus of Elasticity	191,640 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=1,092 mm
Thickness	Ts=20 mm
Corrosion allowance	c=3 mm

Reinforcing pad dimensions

Radius	400 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=400 mm

Geometric parameters

Mean radius $Rm = R - [(Ts - c)/2] = 1{,}083.5$ mm
Total thickness $T = Ts - c = 17$ mm
$U = ro / \sqrt{Rm\ T} = 2.947$

Stress concentration factors

membrane Kn =1.589
bending Kb =1.319

Applied loads

Radial load P = -12,760 daN
Load V_1 = 0 daN
load V_2 = 0 daN
Moment M_1 = 0 daN.m
Moment M_2 = 18,200 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

(MPa)	Points Au	AL	Bu	BL	Cu	CL	Du	DL
(1) Kn (Ny T / P) . P/ T^2	-3.22	-3.22	-3.22	-3.22	-3.22	-3.22	-3.22	-3.22
(2) Kn (Ny T $\sqrt{RmT}$ / M_2)	-18.7	-18.7	18.7	18.7	0	0	0	0
(3) Kn (Ny T $\sqrt{RmT}$ / M_1)	0	0	0	0	0	0	0	0
(4) = (1) + (2) + (3)	-21.92	-21.92	15.47	15.47	-3.22	-3.22	-3.22	-3.22
(5) Pressure	18.19	18.19	18.19	18.19	18.19	18.19	18.19	18.19
(6) = (4) + (5)	-3.73	-3.73	33.66	33.66	14.97	14.97	14.97	14.97
(7) Kb (My / P) . 6 P/ T^2	-7.16	7.16	-7.16	7.16	-7.16	7.16	-7.16	7.16
(8) Kb (My $\sqrt{RmT}$ / M_2) . 6M_2/ (T^2 $\sqrt{RmT}$)	-51.32	51.32	51.32	-51.32	0	0	0	0
(9) Kb (My $\sqrt{RmT}$ / M_1) . 6M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(10) = (7) + (8) +(9)	-58.48	58.48	44.16	-44.16	-7.16	7.16	-7.16	7.16
(11) Kn (Nx T / P) . P/ T^2	-9.11	-9.11	-9.11	-9.11	-9.11	-9.11	-9.11	-9.11
(12) Kn (Nx T $\sqrt{RmT}$ / M_2) . M_2/ (T^2 $\sqrt{RmT}$)	-52.58	-52.58	52.58	52.58	0	0	0	0
(13) Kn (Nx T $\sqrt{RmT}$ / M_1) . M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(14) = (11) + (12) + (13)	-61.69	-61.69	43.47	43.47	-9.11	-9.11	-9.11	-9.11
(15) Pressure	18.19	18.19	18.19	18.19	18.19	18.19	18.19	18.19
(16) = (14) + (15)	-43.49	-43.49	61.66	61.66	9.08	9.08	9.08	9.08
(17) Kb (Mx / P) . 6 P/ T^2	-20.07	20.07	-20.07	20.07	-20.07	20.07	-20.07	20.07
(18) Kb (Mx $\sqrt{RmT}$ / M_2) . 6M_2/ (T^2 $\sqrt{RmT}$)	-185.96	185.96	185.96	-185.96	0	0	0	0
(19) Kb (Mx $\sqrt{RmT}$ / M_1) . 6M_1/ (T^2 $\sqrt{RmT}$)	0	0	0	0	0	0	0	0
(20) (17) + (18) + (19)	-206.03	206.03	165.88	-165.88	-20.07	20.07	-20.07	20.07
Shear stresses								
(21) v1 / Π ro T	0	0	0	0	0	0	0	0
(22) v2 / Π ro T	0	0	0	0	0	0	0	0
(23) Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
σx = (16) + (20)	-249.52	162.54	227.55	-104.22	-10.99	29.16	-10.99	29.16
σy = (6) + (10)	-62.21	54.76	77.83	-10.5	7.81	22.13	7.81	22.13
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) (σy + σx + $\sqrt{((\sigma y - \sigma x)^2 + 4\tau^2}$)² / 2	-62.21	162.54	227.55	-10.5	7.81	29.16	7.81	29.16
(25) (σy + σx - $\sqrt{((\sigma y - \sigma x)^2 + 4\tau^2}$)² / 2	-249.52	54.76	77.83	-104.22	-10.99	22.13	-10.99	22.13
(26) = (24) – (25)	187.31	107.78	149.72	93.73	18.8	7.03	18.8	7.03
(27) = (6) – (16)	39.76	39.76	-28	-28	5.88	5.88	5.88	5.88

	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 249.52 MPa	565.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 61.66 MPa	282.84 MPa (1.5 f)

***U* = 2.947**	Read values	Used values
Fig.SR-2	*0.013*	**NiT/P (Nx) = 0.013**
Fig.SR-2	*0.0057*	**Mi/P (Mx) = 0.0057**
Fig.SR-2	*0.0046*	**NiT/P (Ny) = 0.0046**
Fig.SR-2	*0.002*	**Mi/P (My) = 0.002**
Fig.SR-3	*0.0071*	**NiT(Rm/T)1/2 / M cosθ = 0.0071**
Fig.SR-3	*0.0051*	**Mi(Rm/T)1/2 / M cosθ = 0.0051**
Fig.SR-3	*0.0025*	**NiT(Rm/T)1/2 / M cosθ = 0.0025**
Fig.SR-3	*0.0014*	**Mi(Rm/T)1/2 / M cosθ = 0.0014**

Opening reinforcement V1 int. pressure Vent

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
DESIGN PRESSURE P               0.5800 MPa
TEMPERATURE                     167.0  °C
CORROSION SHELL C /NOZZLE CT                          3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                  193.89 /     193.89 MPa
JOINT EFFICIENCY V                                    1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT              1332.00 /      60.30 mm
THICKNESS SHELL E / NOZZLE ET                        16.00 /       8.80 mm
NOZZLE SCHEDULE
FLANGE RATING                   150.   lb
NOZZLE HEIGHT  H                200.00 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                 63.50 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in OPERATION            * BRANCH CONNECTION ON KORBOGGEN HEAD

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2.3*T-P)....................=      0.08 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 sA = E ................................=     16.00 mm
                 sS = ET ...............................=      8.80 mm
                 di = (DT-2*(ET-CT)) ...................=     48.70 mm
                 Di = 2*(0.8*D+C).......................=   2137.20 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    167.19 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
                 lS = 1.SQRT((di+sS-CT)*(sS-CT)) ........=     17.78 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    167.19 mm
                 lSr=...................................=     17.78 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     2173. mm²
                 As1 = .................................=      179. mm²
                 As2 = .................................=        0. mm²
                 Ap = ..................................=   105551. mm²
                 P*[Ap/(As0+As1+As2)+1/2]               =     26.32 MPa
                                                   <= S =    193.89 MPa
```

Opening reinforcement V1 int. pressure Vent

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NL1
DESIGN PRESSURE P             0.8717 MPa
TEMPERATURE                    20.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 328.57 /     328.57 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT             1332.00 /      60.30 mm
THICKNESS SHELL E / NOZZLE ET                       16.00 /       8.80 mm
NOZZLE SCHEDULE
FLANGE RATING                 150.   lb
NOZZLE HEIGHT  H              200.00 mm
NOZZLE INTERNAL HEIGHT M        0.00 mm
FLANGE HEIGHT EB               63.50 mm
ECCENTRICITY                    0.00 mm
NOZZLE SLOPE ANGLE A            0.00 °

VESSEL in TEST               * BRANCH CONNECTION ON KORBOGGEN HEAD

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2.3*T-P)....................=      0.07 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 sA = E ................................=     16.00 mm
                 sS = ET ...............................=      8.80 mm
                 di = (DT-2*(ET-CT)) ...................=     48.70 mm
                 Di = 2*(0.8*D+C).......................=   2137.20 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    167.19 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
                 lS = 1.SQRT((di+sS-CT)*(sS-CT)) ........=     17.78 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    167.19 mm
                 lSr=...................................=     17.78 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     2173. mm2
                 As1 = .................................=      179. mm2
                 As2 = .................................=        0. mm2
                 Ap = ..................................=   105551. mm2
                 P*[Ap/(As0+As1+As2)+1/2]               =     39.56 MPa
                                                  <= S =    328.57 MPa
```

Opening reinforcement V1 ext. pressure Vent

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                        P355NL1                   P355NL1
EXT. PRESSURE                   0.1030 MPa
TEMPERATURE                     167.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 193.89 /     181.77 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT             1332.00 /      60.30 mm
THICKNESS SHELL E / NOZZLE ET                       16.00 /       8.80 mm
NOZZLE SCHEDULE
FLANGE RATING                   150.   lb
NOZZLE HEIGHT  H                200.00 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                 63.50 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in EXTERNAL PRESSURE    * BRANCH CONNECTION ON KORBOGGEN HEAD

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =...................................=      0.31 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 sA = E .................................=     16.00 mm
                 sS = ET ................................=      8.80 mm
                 di = (DT-2*(ET-CT)) ....................=     48.70 mm
                 Di = 2*(0.8*D+C)........................=   2137.20 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    167.19 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
                 lS = 1.SQRT((di+sS-CT)*(sS-CT)) ........=     17.78 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =....................................=    167.19 mm
                 lSr=....................................=     17.78 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = ..................................=     2173. mm2
                 As1 = ..................................=      179. mm2
                 As2 = ..................................=        0. mm2
                 Ap = ...................................=   105551. mm2
                 (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =   453751. N
                                              >= P*Ap =    10872. N
```

Opening reinforcement T   int. pressure Thermowell

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NH
DESIGN PRESSURE P               0.5800 MPa
TEMPERATURE                     167.0  °C
CORROSION SHELL C /NOZZLE CT                             3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                     193.89 /     178.80 MPa
JOINT EFFICIENCY V                                       1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT                  813.00 /      84.00 mm
THICKNESS SHELL E / NOZZLE ET                           16.00 /      16.60 mm
NOZZLE SCHEDULE
FLANGE RATING                   150.   lb
NOZZLE HEIGHT  H                249.00 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                 19.05 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in OPERATION            * BRANCH CONNECTION ON NOZZLE         *L.W.N*

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =DT*P/(2.3*T-P)....................=      0.12 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 sA = E ................................=     16.00 mm
                 sS = ET ...............................=     16.60 mm
                 di = (DT-2*(ET-CT)) ...................=     56.80 mm
                 Di = D-2*(E-C).........................=    787.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    101.98 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=     38.68 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =...................................=    101.98 mm
                 lSr=...................................=     38.68 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = .................................=     1326. mm²
                 As1 = .................................=      703. mm²
                 As2 = .................................=        0. mm²
                 Ap = ..................................=    58124. mm²
                 (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =   382125. N
                                                >= P*Ap =    33712. N
```

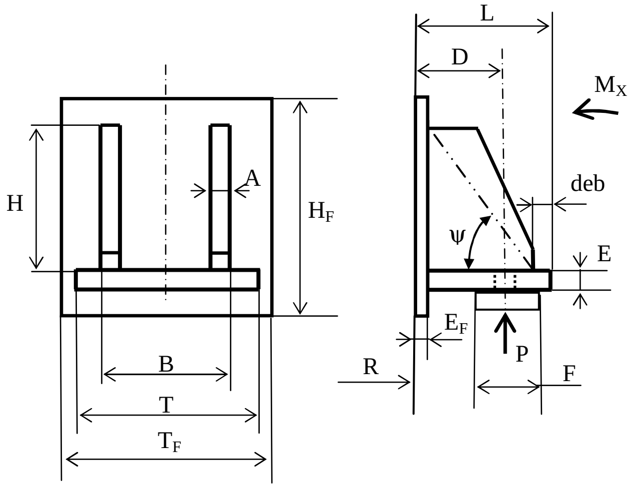
Opening reinforcement T int. pressure Thermowell

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                       P355NL1                    P355NH
DESIGN PRESSURE P               0.8717 MPa
TEMPERATURE                       20.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 328.57 /     290.48 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT              813.00 /      84.00 mm
THICKNESS SHELL E / NOZZLE ET                       16.00 /      16.60 mm
NOZZLE SCHEDULE
FLANGE RATING                   150.   lb
NOZZLE HEIGHT  H                249.00 mm
NOZZLE INTERNAL HEIGHT M          0.00 mm
FLANGE HEIGHT EB                 19.05 mm
ECCENTRICITY                      0.00 mm
NOZZLE SLOPE ANGLE A              0.00 °

VESSEL in TEST                 * BRANCH CONNECTION ON NOZZLE         *L.W.N*

       ** NOZZLE MINIMAL THICKNESS
                ET0 =DT*P/(2.3*T-P)....................=      0.11 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                sA = E ................................=     16.00 mm
                sS = ET ...............................=     16.60 mm
                di = (DT-2*(ET-CT)) ...................=     56.80 mm
                Di = D-2*(E-C).........................=    787.00 mm
            3-THEORICAL REINFORCEMENT AREA
                b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    101.98 mm
                psi = Nozzle deflection angle / shell   =     90.00 °.
              lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=     38.68 mm
            4-AVAILABLE REINFORCEMENT AREA
                br =...................................=    101.98 mm
                lSr=...................................=     38.68 mm
       B-VERIFICATION OF REINFORCEMENT
                As0 = .................................=     1326. mm²
                As1 = .................................=      703. mm²
                As2 = .................................=        0. mm²
                Ap = ..................................=    58124. mm²
                (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =   638870. N
                                               >= P*Ap =    50669. N
```

Opening reinforcement T ext. pressure Thermowell

```
DESIGN CODE         AD MERK. -B1 AND B10 MATERIAL :  SHELL     /  NOZZLE
                                         P355NL1                   P355NH
EXT. PRESSURE                 0.1030 MPa
TEMPERATURE                   167.0  °C
CORROSION SHELL C /NOZZLE CT                         3.00 /       3.00 mm
ALLOWABLE STRESS AT DESIGN TEMPERATURE
SHELL S / NOZZLE T                                 181.77 /     167.62 MPa
JOINT EFFICIENCY V                                   1.00
OUTSIDE DIAMETER SHELL  D / NOZZLE DT              813.00 /      84.00 mm
THICKNESS SHELL E / NOZZLE ET                       16.00 /      16.60 mm
NOZZLE SCHEDULE
FLANGE RATING                 150.   lb
NOZZLE HEIGHT  H              249.00 mm
NOZZLE INTERNAL HEIGHT M        0.00 mm
FLANGE HEIGHT EB               19.05 mm
ECCENTRICITY                    0.00 mm
NOZZLE SLOPE ANGLE A            0.00 °

VESSEL in EXTERNAL PRESSURE    * BRANCH CONNECTION ON NOZZLE         *L.W.N*

       ** NOZZLE MINIMAL THICKNESS
                 ET0 =....................................=      0.42 mm

       A-REQUIRED DIMENSIONS FOR THE REINFORCEMENT
            1-DESIGN PARAMETERS
                 sA = E .................................=     16.00 mm
                 sS = ET ................................=     16.60 mm
                 di = (DT-2*(ET-CT)) ....................=     56.80 mm
                 Di = D-2*(E-C)..........................=    787.00 mm
            3-THEORICAL REINFORCEMENT AREA
                 b = MAX(SQRT((Di+sA-C)*(sA-C)),3*sA) ...=    101.98 mm
                 psi = Nozzle deflection angle / shell   =     90.00 °.
               lS=(1+.25*psi/90)*SQRT((di+sS-CT)*(sS-CT))=     38.68 mm
            4-AVAILABLE REINFORCEMENT AREA
                 br =....................................=    101.98 mm
                 lSr=....................................=     38.68 mm
       B-VERIFICATION OF REINFORCEMENT
                 As0 = ..................................=     1326. mm²
                 As1 = ..................................=      703. mm²
                 As2 = ..................................=        0. mm²
                 Ap = ...................................=    58124. mm²
                 (S-P/2)*As0+(T-P/2)*As1+(R-P/2)*As2     =   358694. N
                                                >= P*Ap =     5987. N
```

Support bracket check
in operation



Vessel axis distance : R = 666 mm
Vertical load on 1 support : P = 8,601.9 daN
Moment : M_X = 0 daN.mm

Standard : /
Material : P355NL1
Allowable stress: σa = 134.67 MPa
Yield strength : Ys = 202 MPa
Number : ns = 2

Base Plate :	L = 323 mm
	E = 26 mm
	T = 354 mm
	D = 247 mm
Gussets :	Nombre N = 2
	B = 280 mm
	H = 434 mm
	A = 16 mm
	deb = 20 mm
Support beam :	F = 130 mm
Wear plate :	H_F = 560 mm
	T_F = 450 mm
	E_F = 16 mm

Weld seams and metal equivalent section checking

Vertical load : $F_v = P + [(4 |M_X| / 2(R+D))/ns]$ = 8,601.9 daN   Bending moment : $M = F_v D$ = 2,124,667 daN.mm

Shear : S_w = 2 N H m = 19,443.2 mm²   m = 0.7 min (A ,E_F) = 11.2 mm $\sigma_{cis} = 4/3\, F_v/S_w$ = 5.9 MPa

Welds :	Under the base plate :	s_A = T m = 3,964.8 mm²	y_A = m / 2 = 5.6 mm
	Above the base plate :	s_B = T m = 3,964.8 mm²	$y_B = m + E + x_A$ = 42.8 mm
	Gussets :	s_C = 2 N (H-m) m = 18,941.4 mm²	y_C = m + E + m + H/2 = 265.4 mm

Distance axis of inertia / bottom weld : $y = (s_A y_A + s_B y_B + s_C y_C) / (s_A + s_B + s_C)$ = 194.22 mm
Equivalent section inertia : I = 582,354,300 mm^4
Bending stress : σ_{flex} = 4/3 max (y, m+E+T–y) M/I = 13.47 MPa
Reduction factor : α = min [0.8 (1+(1/m), 1] = 0.8714

$\sigma_{Tot} = \sqrt{\sigma_{flex}^2 + 1.8\sigma_{cis}^2}$ = 15.63 MPa ≤ σ_{MAX} = α Ys = 176.03 MPa

Base plate checking

Bending moment :
$M_1 = F_V [(T-B+A)/2]^2 /2\, T$ = 24,603 daN.mm $M_2 = F_V [0.25\, T - (T-B+A)/2] /2$ = 187,091 daN.mm
M = max (M_1, M_2) = 187,091 daN.mm   I/v = M / σa = 13,893 mm³

Required thickness : $E_{min} = \sqrt{\frac{6I/v}{F}}$ = 25.32 mm

Gusset checking

ψ = Arc tg (H/[L-E_F-deb]) = 54.88 °   Compression allowable stress : σc = ¾ Ys
Equivalent width : b = (L – D – deb + F/2) sin ψ = 99.21 mm
Compression load : Q = (F_V / N) sin ψ = 3,526.5 daN
Required thickness : A_{min} = (Q / b) (10 / σc) = 2.35 mm

Bolting (M24)

Number n_b = 2   Diameter d_b = 24 mm   area (1 bolt) s_b = 324.3 mm²
Tensile stress : $F_V / (n_b s_b)$ = 0 MPa ≤ 100 MPa

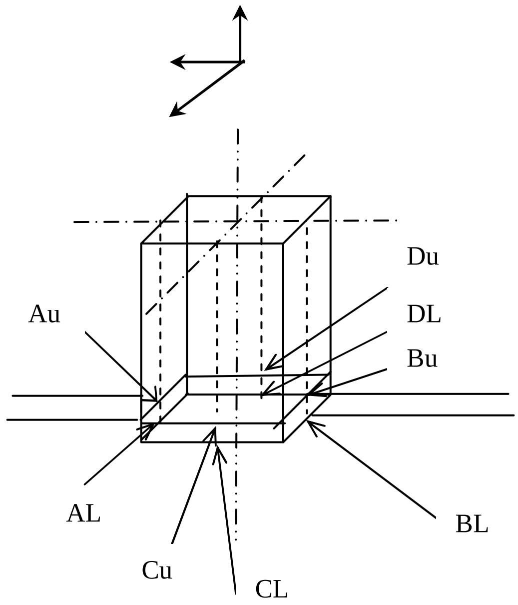
LURGI LURGIALLEE 5 FRANKFURT - GERMANY	Design Calculations Deisohexanizer Reboiler E-610	29 July 2010 Revision : 0 Ref. 1.04962

Local Loads due to Brackets.

Local loads Support (1), Loaded Area on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Design pressure code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	0.58 MPa
Existing circular stress	/
Existing longitudinale stress	/
Allowable stress	f = 193.89 MPa
Yield strength	290.84 MPa
Modulus of elasticity	191,640 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R = 666 mm
Thickness	Ts = 16 mm
Corrosion allowance	c = 3 mm

Reinforcing pad dimensions

Thickness Tr	16 mm

Dimensions Loaded Area

Fillet radius	15.21 mm
1/2 Longitudinal length	c2 = 230.5 mm
1/2 Circumferential length	c1 = 177 mm

Geométric parameters

Mean radius Rm = (R + Tr) - [(Tr + Ts -c)/2] = 667.5 mm

Total thickness T = Tr + Ts - c = 29 mm

γ = Rm / T = 23.017

$\beta 1$ = c1 / Rm = 0.265 $\beta 2$ = c2 / Rm = 0.345 $0.25 \le \beta 1/\beta 2 \le 4$

β calculation:

Radial load P :

$$\beta = \left[1 - \frac{1}{3}\left(\frac{\beta_1}{\beta_2} - 1\right)(1 - K1)\right]\sqrt{\beta_1 \beta_2} \quad (\text{if } \beta 1 / \beta 2 > 1)$$

$$\beta = \left[1 - \frac{4}{3}\left(1 - \frac{\beta_1}{\beta_2}\right)(1 - K2)\right]\sqrt{\beta_1 \beta_2} \quad (\text{if } \beta 1 / \beta 2 < 1)$$

Moment Mc : $\beta = Kc\sqrt[3]{\beta_2\,\beta_1^2)}$ Moment ML : $\beta = KL\sqrt[3]{\beta_1\,\beta_2^2)}$

	Radial load P			Bending moment Mc			Bending moment ML		
	K1	K2	β	Cc	Kc	β	CL	KL	β
Nϕ	0.91	1.48	0.348	0.812	1.00	0.29	0.884	1.00	0.316
Nx	1.68	1.2	0.321	0.845	1.00	0.29	1.038	1.00	0.316
Mϕ	1.76	0.88	0.291	/	1.106	0.32	/	1.002	0.317
Mx	1.2	1.25	0.326	/	1.281	0.371	/	1.079	0.341

Stress concentration factors

membrane Kn = 1
bending Kb = 1

Applied loads

Radial P = 0 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 0 daN.m
Bending moment ML = -2,125.61 daN.m
Torsionnal moment Mt = 0 daN.m

Maximum values of loads :

Case with no moment : P = 6,558.1 daN

Case with no radial load : ML = 556.49 daN.m ; Mc = 433.51 daN.m

Stresses on Loaded Area

(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
Longitudinal stresses								
(1) Kn (Nx / P / Rm) . P/ (RmT)	0	0	0	0	0	0	0	0
(2) Kn Cc (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	0	0	0	0
(3) Kn CL (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	5.1	5.1	-5.1	-5.1	0	0	0	0
(4) = (1) + (2) + (3)	5.1	5.1	-5.1	-5.1	0	0	0	0
(5) Pressure	14.78	14.78	14.78	14.78	14.78	14.78	14.78	14.78
(6) = (4) + (5)	19.88	19.88	9.68	9.68	14.78	14.78	14.78	14.78
(7) Kb (Mx / P) . 6 P/ T^2	0	0	0	0	0	0	0	0
(8) Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	0	0	0	0
(9) Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	20	-20	-20	20	0	0	0	0
(10) = (7) + (8) + (9)	20	-20	-20	20	0	0	0	0
Circumferential stresses								
(11) Kn (Nϕ / P / Rm) . P/ Rm / T	0	0	0	0	0	0	0	0
(12) Kn Cc (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	0	0	0	0
(13) Kn CL (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	9.69	9.69	-9.69	-9.69	0	0	0	0
(14) = (11) + (12) + (13)	9.69	9.69	-9.69	-9.69	0	0	0	0
(15) Pressure	29.56	29.56	29.56	29.56	29.56	29.56	29.56	29.56
(16) = (14) + (15)	39.25	39.25	19.86	19.86	29.56	29.56	29.56	29.56
(17) Kb (Mϕ / P) . 6 P/ T^2	0	0	0	0	0	0	0	0
(18) Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	0	0	0	0
(19) Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	13.14	-13.14	-13.14	13.14	0	0	0	0
(20) = (17) + (18) + (19)	13.14	-13.14	-13.14	13.14	0	0	0	0
Shear stresses								
(21) Vc / 4 c1 T	0	0	0	0	0	0	0	0
(22) VL / 4 c2 T	0	0	0	0	0	0	0	0
σx = (6) + (10)	39.88	-0.13	-10.32	29.68	14.78	14.78	14.78	14.78
σϕ = (16) + (20)	52.39	26.12	6.73	33	29.56	29.56	29.56	29.56
τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24) $(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	52.39	26.12	6.73	33	29.56	29.56	29.56	29.56
(25) $(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	39.88	-0.13	-10.32	29.68	14.78	14.78	14.78	14.78
(26) = (24) – (25)	12.51	26.24	17.05	3.32	14.78	14.78	14.78	14.78
(27) = (6) – (16)	-19.37	-19.37	-10.18	-10.18	-14.78	-14.78	-14.78	-14.78

	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 52.39 MPa	581.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 39.25 MPa	290.84 MPa (1.5 f)

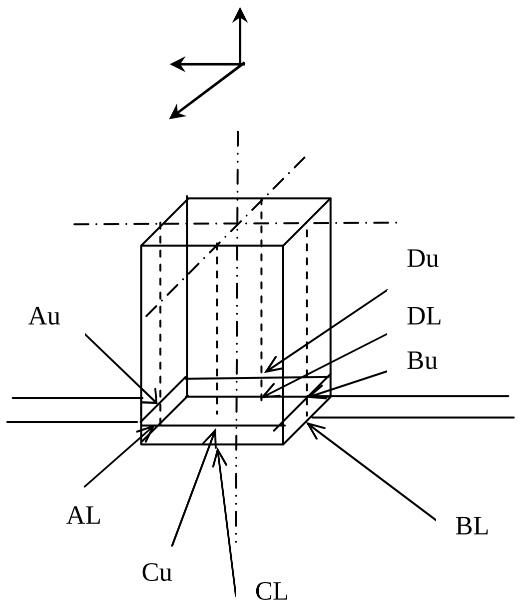
		Read values	Used values
Fig. 3B	γ=25	(β = 0.316) 2.2258	
Fig. 3B	γ=15	(β = 0.316) 1.6315	**Nϕ/(ML/Rm2 β) = 2.108**
Fig. 4B	γ=25	(β = 0.316) 1.0189	
Fig. 4B	γ=15	(β = 0.316) 0.6437	**Nx/(ML/Rm2 β) = 0.9445**
Fig. 1B	γ=25	(β = 0.317) 0.0183	
Fig. 1B	γ=15	(β = 0.317) 0.0257	**Mϕ/(ML/Rm β) = 0.0197**
Fig. 2B	γ=25	(β = 0.341) 0.0276	
Fig. 2B	γ=15	(β = 0.341) 0.0401	**Mx/(ML/Rm β) = 0.0301**

Local loads Support (1), At the edge of reinforcing pad on cylindrical shell

WRC 107 Bulletin March 1979

Design pressure code : AD-MERKBLAETTER 2000 (11-2007)

Sign convention for loads and moments



Design pressure	0.58 MPa
Existing circular stress	/
Existing longitudinale stress	/
Allowable stress	f = 193.89 MPa
Yield strength	290.84 MPa
Modulus of elasticity	191,640 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius R = 666 mm
Thickness Ts = 16 mm
Corrosion allowance c = 3 mm

Reinforcing pad dimensions

1/2 Longitudinal length 280 mm
1/2 Circumferential length 229.52 mm

Dimensions Loaded Area

Fillet radius 15.21 mm
1/2 Longitudinal length c2 = 280 mm
1/2 Circumferential length c1 = 229.5161 mm

Geométric parameters

Mean radius Rm = R - [(Ts -c)/2] = 659.5 mm
Total thickness T = Ts - c = 13 mm

γ = Rm / T = 50.731

$\beta1$ = c1 / Rm = 0.348 $\beta2$ = c2 / Rm = 0.425 $0.25 \leq \beta1/\beta2 \leq 4$

β calculation:

Radial load P :

$$\beta=\left[1-\frac{1}{3}\left(\frac{\beta_1}{\beta_2}-1\right)(1-K1)\right]\sqrt{\beta_1\beta_2}$$ (if $\beta1 / \beta2 > 1$)

$$\beta=\left[1-\frac{4}{3}\left(1-\frac{\beta_1}{\beta_2}\right)(1-K2)\right]\sqrt{\beta_1\beta_2}$$ (if $\beta1 / \beta2 < 1$)

Moment Mc : $\beta=Kc\sqrt[3]{\beta_2\,\beta_1^2}$ Moment ML : $\beta=KL\sqrt[3]{\beta_1\,\beta_2^2}$

	Radial load P			Bending moment Mc			Bending moment ML		
	K1	K2	β	Cc	Kc	β	CL	KL	β
Nϕ	0.91	1.48	0.429	0.786	1.00	0.372	0.889	1.00	0.397
Nx	1.68	1.2	0.403	0.851	1.00	0.372	0.971	1.00	0.397
Mϕ	1.76	0.88	0.373	/	1.096	0.408	/	1.001	0.398
Mx	1.2	1.25	0.407	/	1.235	0.459	/	1.064	0.423

Stress concentration factors

membrane Kn = 1
bending Kb = 1

Applied loads

Radial P = 0 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 0 daN.m
Bending moment ML = -2,125.61 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

		Points							
	(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses								
(1)	Kn (Nx / P / Rm) . P/ (RmT)	0	0	0	0	0	0	0	0
(2)	Kn Cc (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	0	0	0	0
(3)	Kn CL (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	12.47	12.47	-12.47	-12.47	0	0	0	0
(4)	= (1) + (2) + (3)	12.47	12.47	-12.47	-12.47	0	0	0	0
(5)	Pressure	14.78	14.78	14.78	14.78	14.78	14.78	14.78	14.78
(6)	= (4) + (5)	27.25	27.25	2.31	2.31	14.78	14.78	14.78	14.78
(7)	Kb (Mx / P) . 6 P/ T^2	0	0	0	0	0	0	0	0
(8)	Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	0	0	0	0
(9)	Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	21.17	-21.17	-21.17	21.17	0	0	0	0
(10)	= (7) + (8) + (9)	21.17	-21.17	-21.17	21.17	0	0	0	0
	Circumferential stresses								
(11)	Kn (Nϕ / P / Rm) . P/ Rm / T	0	0	0	0	0	0	0	0
(12)	Kn Cc (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	0	0	0	0
(13)	Kn CL (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	19.52	19.52	-19.52	-19.52	0	0	0	0
(14)	= (11) + (12) + (13)	19.52	19.52	-19.52	-19.52	0	0	0	0
(15)	Pressure	29.56	29.56	29.56	29.56	29.56	29.56	29.56	29.56
(16)	= (14) + (15)	49.08	49.08	10.04	10.04	29.56	29.56	29.56	29.56
(17)	Kb (Mϕ / P) . 6 P/ T^2	0	0	0	0	0	0	0	0
(18)	Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	0	0	0	0
(19)	Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	15.23	-15.23	-15.23	15.23	0	0	0	0
(20)	= (17) + (18) + (19)	15.23	-15.23	-15.23	15.23	0	0	0	0
	Shear stresses								
(21)	Vc / 4 c1 T	0	0	0	0	0	0	0	0
(22)	VL / 4 c2 T	0	0	0	0	0	0	0	0
	σx = (6) + (10)	48.43	6.08	-18.87	23.48	14.78	14.78	14.78	14.78
	σϕ = (16) + (20)	64.31	33.84	-5.2	25.27	29.56	29.56	29.56	29.56
	τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24)	$(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	64.31	33.84	-5.2	25.27	29.56	29.56	29.56	29.56
(25)	$(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2}\ )^2\ / 2$	48.43	6.08	-18.87	23.48	14.78	14.78	14.78	14.78
(26)	= (24) – (25)	15.89	27.77	13.67	1.79	14.78	14.78	14.78	14.78
(27)	= (6) – (16)	-21.83	-21.83	-7.73	-7.73	-14.78	-14.78	-14.78	-14.78

	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 64.31 MPa	581.68 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 49.08 MPa	290.84 MPa (1.5 f)

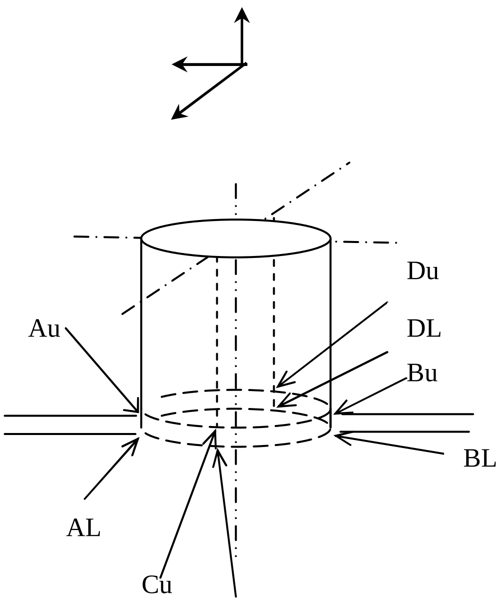
		Read values		Used values
Fig. 3B	γ=75	(β = 0.397)	2.734	
Fig. 3B	γ=50	(β = 0.397)	2.3089	**Nϕ/(ML/Rm2 β) = 2.3213**
Fig. 4B	γ=75	(β = 0.397)	1.52	
Fig. 4B	γ=50	(β = 0.397)	1.3523	**Nx/(ML/Rm2 β) = 1.3572**
Fig. 1B	γ=75	(β = 0.398)	0.004	
Fig. 1B	γ=50	(β = 0.398)	0.0057	**Mϕ/(ML/Rm β) = 0.0056**
Fig. 2B	γ=75	(β = 0.423)	0.0052	
Fig. 2B	γ=50	(β = 0.423)	0.0079	**Mx/(ML/Rm β) = 0.0078**

Local loads due to Trunnions.

Local loads Trunnion (1), Loaded Area on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	/
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=328.57 MPa
Yield strength	345 MPa
Modulus of Elasticity	201,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=0 mm

Reinforcing pad dimensions

Thickness Tr	15 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=136.5 mm

Geometric parameters

Mean radius Rm = (R + Tr) - [(Tr + Ts -c)/2] = 665.5 mm
Total thickness T = Tr + Ts - c = 31 mm
γ = Rm / T = 21.468
β = 0.875 ro / Rm = 0.179

Stress concentration factors

membrane Kn =1
bending Kb =1

Applied loads

Radial P = -8,560.635 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 0 daN.m
Bending moment ML = 1,712.127 daN.m
Torsionnal moment Mt = 0 daN.m

Maximum values of loads :
Case with no moment : P = 6,558.1 daN
Case with no radial load : ML = 556.49 daN.m ; Mc = 433.51 daN.m

Stresses on Loaded Area

(MPa)		Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses								
(1)	Kn (Nx / P / Rm) . P/ (RmT)	-11.23	-11.23	-11.23	-11.23	-14.43	-14.43	-14.43	-14.43
(2)	Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	0	0	0	0
(3)	Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-5.34	-5.34	5.34	5.34	0	0	0	0
(4)	= (1) + (2) + (3)	-16.57	-16.57	-5.88	-5.88	-14.43	-14.43	-14.43	-14.43
(5)	Pressure	0	0	0	0	0	0	0	0
(6)	= (4) + (5)	-16.57	-16.57	-5.88	-5.88	-14.43	-14.43	-14.43	-14.43
(7)	Kb (Mx / P) . 6 P/ T^2	-52.53	52.53	-52.53	52.53	-33.95	33.95	-33.95	33.95
(8)	Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	0	0	0	0
(9)	Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-56.29	56.29	56.29	-56.29	0	0	0	0
(10)	= (7) + (8) + (9)	-108.82	108.82	3.76	-3.76	-33.95	33.95	-33.95	33.95
	Circumferential stresses								
(11)	Kn (Nϕ / P / Rm) . P/ Rm / T	-14.43	-14.43	-14.43	-14.43	-11.23	-11.23	-11.23	-11.23
(12)	Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	0	0	0	0
(13)	Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-16.81	-16.81	16.81	16.81	0	0	0	0
(14)	= (11) + (12) + (13)	-31.24	-31.24	2.38	2.38	-11.23	-11.23	-11.23	-11.23
(15)	Pressure	0	0	0	0	0	0	0	0
(16)	= (14) + (15)	-31.24	-31.24	2.38	2.38	-11.23	-11.23	-11.23	-11.23
(17)	Kb (Mϕ / P) . 6 P/ T^2	-34.37	34.37	-34.37	34.37	-51.25	51.25	-51.25	51.25
(18)	Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	0	0	0	0
(19)	Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-34.58	34.58	34.58	-34.58	0	0	0	0
(20)	= (17) + (18) + (19)	-68.95	68.95	0.21	-0.21	-51.25	51.25	-51.25	51.25
	Shear stresses								
(21)	Vc / Π ro T	0	0	0	0	0	0	0	0
(22)	VL / Π ro T	0	0	0	0	0	0	0	0
(23)	Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
	σx = (6) + (10)	-125.39	92.25	-2.12	-9.64	-48.38	19.53	-48.38	19.53
	σϕ = (16) + (20)	-100.19	37.71	2.59	2.17	-62.48	40.03	-62.48	40.03
	τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24)	$(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-100.19	92.25	2.59	2.17	-48.38	40.03	-48.38	40.03
(25)	$(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-125.39	37.71	-2.12	-9.64	-62.48	19.53	-62.48	19.53
(26)	= (24) – (25)	25.2	54.53	4.71	11.81	14.1	20.5	14.1	20.5
(27)	= (6) – (16)	14.67	14.67	-8.26	-8.26	-3.2	-3.2	-3.2	-3.2

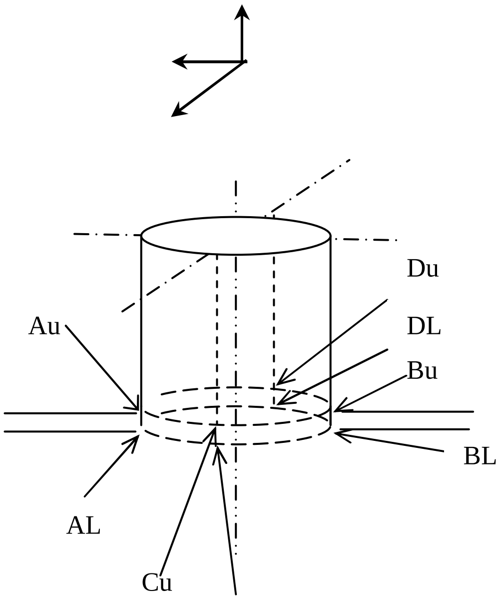
	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 125.39 MPa	985.71 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 31.24 MPa	492.86 MPa (1.5 f)

β = 0.179		Read values	Used values
Fig. 3C Fig. 3C	γ=50 γ=15	4.8271 2.2242	**(Pts A,B) Nx/P/Rm = 2.7052**
Fig. 4C Fig. 4C	γ=25 γ=15	3.9695 2.5753	**(Pts C,D) Nx/P/Rm = 3.4771**
Fig. 4C Fig. 4C	γ=25 γ=15	3.9695 2.5753	**(Pts A,B) Nϕ/P/Rm = 3.4771**
Fig. 3C Fig. 3C	γ=50 γ=15	4.8271 2.2242	**(Pts C,D) Nϕ/P/Rm = 2.7052**
Fig. 2C-1 Fig. 2C-1	γ=25 γ=15	0.058 0.0758	**(Pts A,B) Mϕ/P = 0.0643**
Fig. 1C Fig. 1C	γ=25 γ=15	0.0899 0.1069	**(Pts C,D) Mϕ/P = 0.0959**
Fig. 1C-1 Fig. 1C-1	γ=25 γ=15	0.0925 0.1088	**(Pts A,B) Mx/P = 0.0983**
Fig. 2C Fig. 2C	γ=25 γ=15	0.0572 0.075	**(Pts C,D) Mx/P = 0.0635**
Fig. 3B Fig. 3B	γ=25 γ=15	2.85 1.63	**Nϕ/(ML/Rm2 β) = 2.4191**
Fig. 4B Fig. 4B	γ=25 γ=15	0.921 0.491	**Nx/(ML/Rm2 β) = 0.7691**
Fig. 1B Fig. 1B	γ=25 γ=15	0.0357 0.044	**Mϕ/(ML/Rm β) = 0.0386**
Fig. 2B Fig. 2B	γ=25 γ=15	0.0593 0.0695	**Mx/(ML/Rm β) = 0.0629**

Local loads Trunnion (1), At the edge of reinforcing pad on cylindrical shell

WRC 107 Bulletin March 1979

Sign convention for loads and moments



Pressure design code : AD-MERKBLAETTER 2000 (11-2007)

Design pressure	/
Existing circular stress	/
Existing longitudinal stress	/
Allowable stress	f=328.57 MPa
Yield strength	345 MPa
Modulus of Elasticity	201,000 MPa
Joint efficiency	1
Membrane stress factor	1.5
Design stress factor	3

Shell dimensions

External radius	R=666 mm
Thickness	Ts=16 mm
Corrosion allowance	c=0 mm

Reinforcing pad dimensions

Radius 240 mm

Dimensions of Loaded Area

Fillet radius	15.21 mm
External radius	ro=240 mm

Geometric parameters

Mean radius Rm = R - [(Ts -c)/2] = 658 mm
Total thickness T = Ts - c = 16 mm
γ = Rm / T = 41.125
β = 0.875 ro / Rm = 0.319

Stress concentration factors

membrane Kn =1
bending Kb =1

Applied loads

Radial P = -8,560.635 daN
Shear Vc = 0 daN
Shear VL = 0 daN
Bending moment Mc = 0 daN.m
Bending moment ML = 1,712.127 daN.m
Torsionnal moment Mt = 0 daN.m

Stresses on At the edge of reinforcing pad

		Points							
	(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses								
(1)	Kn (Nx / P / Rm) . P/ (RmT)	-16.45	-16.45	-16.45	-16.45	-35.14	-35.14	-35.14	-35.14
(2)	Kn (Nx / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	0	0	0	0
(3)	Kn (Nx / ML / Rm^2 β) . ML / (Rm^2 β T)	-11.43	-11.43	11.43	11.43	0	0	0	0
(4)	= (1) + (2) + (3)	-27.89	-27.89	-5.02	-5.02	-35.14	-35.14	-35.14	-35.14
(5)	Pressure	0	0	0	0	0	0	0	0
(6)	= (4) + (5)	-27.89	-27.89	-5.02	-5.02	-35.14	-35.14	-35.14	-35.14
(7)	Kb (Mx / P) . 6 P/ T^2	-68.88	68.88	-68.88	68.88	-26.96	26.96	-26.96	26.96
(8)	Kb (Mx / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	0	0	0	0
(9)	Kb (Mx / ML / Rm β) . 6 ML / (Rm β T^2)	-35.09	35.09	35.09	-35.09	0	0	0	0
(10)	= (7) + (8) + (9)	-103.97	103.97	-33.79	33.79	-26.96	26.96	-26.96	26.96
	Circumferential stresses								
(11)	Kn (Nϕ / P / Rm) . P/ Rm / T	-35.14	-35.14	-35.14	-35.14	-16.45	-16.45	-16.45	-16.45
(12)	Kn (Nϕ / Mc / Rm^2 β) . Mc / (Rm^2 β T)	0	0	0	0	0	0	0	0
(13)	Kn (Nϕ / ML / Rm^2 β) . ML / (Rm^2 β T)	-21.63	-21.63	21.63	21.63	0	0	0	0
(14)	= (11) + (12) + (13)	-56.76	-56.76	-13.51	-13.51	-16.45	-16.45	-16.45	-16.45
(15)	Pressure	0	0	0	0	0	0	0	0
(16)	= (14) + (15)	-56.76	-56.76	-13.51	-13.51	-16.45	-16.45	-16.45	-16.45
(17)	Kb (Mϕ / P) . 6 P/ T^2	-28.55	28.55	-28.55	28.55	-74.38	74.38	-74.38	74.38
(18)	Kb (Mϕ / Mc / Rm β) . 6 Mc / (Rm β T^2)	0	0	0	0	0	0	0	0
(19)	Kb (Mϕ / ML / Rm β) . 6 ML / (Rm β T^2)	-21.76	21.76	21.76	-21.76	0	0	0	0
(20)	= (17) + (18) + (19)	-50.31	50.31	-6.79	6.79	-74.38	74.38	-74.38	74.38
	Shear stresses								
(21)	Vc / Π ro T	0	0	0	0	0	0	0	0
(22)	VL / Π ro T	0	0	0	0	0	0	0	0
(23)	Mt / 2 Π ro^2 T	0	0	0	0	0	0	0	0
	σx = (6) + (10)	-131.85	76.08	-38.81	28.77	-62.1	-8.17	-62.1	-8.17
	σϕ = (16) + (20)	-107.08	-6.45	-20.3	-6.72	-90.83	57.92	-90.83	57.92
	τ = (21) + (22) + (23)	0	0	0	0	0	0	0	0
(24)	$(\sigma\phi + \sigma x + \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-107.08	76.08	-20.3	28.77	-62.1	57.92	-62.1	57.92
(25)	$(\sigma\phi + \sigma x - \sqrt{((\sigma\Phi - \sigma x)^2 + 4\tau^2})^2 / 2$	-131.85	-6.45	-38.81	-6.72	-90.83	-8.17	-90.83	-8.17
(26)	= (24) – (25)	24.77	82.53	18.51	35.49	28.73	66.1	28.73	66.1
(27)	= (6) – (16)	28.88	28.88	8.49	8.49	-18.68	-18.68	-18.68	-18.68

	calculated	allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 131.85 MPa	985.71 MPa (3 f)
Membrane stress	Max [|(6)| , |(16)| , |(27)|] = 56.76 MPa	492.86 MPa (1.5 f)

***β* = 0.319**		Read values	Used values
Fig. 3C Fig. 3C	γ=50 γ=15	2.1993 1.5057	**(Pts A,B) Nx/P/Rm = 2.0234**
Fig. 4C Fig. 4C	γ=50 γ=35	5.019 3.8394	**(Pts C,D) Nx/P/Rm = 4.3211**
Fig. 4C Fig. 4C	γ=50 γ=35	5.019 3.8394	**(Pts A,B) Nϕ/P/Rm = 4.3211**
Fig. 3C Fig. 3C	γ=50 γ=15	2.1993 1.5057	**(Pts C,D) Nϕ/P/Rm = 2.0234**
Fig. 2C-1 Fig. 2C-1	γ=50 γ=35	0.0117 0.016	**(Pts A,B) Mϕ/P = 0.0142**
Fig. 1C Fig. 1C	γ=50 γ=35	*0.0338* *0.0393*	**(Pts C,D) Mϕ/P = 0.0371**
Fig. 1C-1 Fig. 1C-1	γ=50 γ=35	0.0302 0.0372	**(Pts A,B) Mx/P = 0.0343**
Fig. 2C Fig. 2C	γ=50 γ=35	*0.0128* *0.0139*	**(Pts C,D) Mx/P = 0.0134**
Fig. 3B Fig. 3B	γ=50 γ=35	3.0834 2.5922	**Nϕ/(ML/Rm2 β) = 2.7927**
Fig. 4B Fig. 4B	γ=50 γ=35	1.6838 1.3329	**Nx/(ML/Rm2 β) = 1.4762**
Fig. 1B Fig. 1B	γ=50 γ=35	0.0089 0.0131	**Mϕ/(ML/Rm β) = 0.0114**
Fig. 2B Fig. 2B	γ=50 γ=35	0.0134 0.0218	**Mx/(ML/Rm β) = 0.0184**

Minimum Design Metal Temperature

AD-MERKBLAETTER 2000 (11-2007)
Materials for Pressure Vessels - W10.
Materials for low temperatures - Ferrous materials.

MDMT	minimum design metal temperature

MDMT for each component.

		Material	MDMT (°C)
01 KH	TS01	P355NL1	-40
02 SH	TS02	P355NL1	-40
03 EF	GF01	P355NH	0
05 TT	TT01	P355NH	0
06 SH	SS01	P355NL1	-40
07 SH	SS01	P355NL1	-40
08 TT	TT02	P355NH	0
10 EF	GF02	P355NH	0
11 SH	TS03	P355NL1	-40
12 KH	TS04	P355NL1	-40
Nozzle	I1	P355NL1	-40
Nozzle	O1	P355NL1	-40
Nozzle	O2	P355NL1	-40
Nozzle	I2	P355NL1	-40
Nozzle	V1	P355NL1	-40
Nozzle	T	P355NH	0
Flange	I1	P355NH	0
Flange	O1	P355NH	0
Flange	O2	P355NH	0
Flange	I2	P355NH	0
Flange	V1	P355NH	0
Tubes.		P355NL1	-40

Shell (comp. 1) : Rated MDMT 0 °C > Design MDMT -36 °C condition not maintained

PED: impact tests are required at the lowest operating temperature (-36 °C).

Tube (comp. 2) : Rated MDMT 0 °C > Design MDMT -36 °C condition not maintained

PED: impact tests are required at the lowest operating temperature (-36 °C).

The values in red in the last column indicates that a impact test is required for the corresponding element.

Nozzles Flexibilities.

The following flexibilities, computed per BS/PD 5500 Annex G, should be used in a piping, "beam-type" analysis of the intersection. The flexibilities should be inserted at the surface of the branch/header or nozzle-vessel junction.

Nozzle		Level of stiffening line (*)		Axial Translational Flexibility (mm / daN)	Rotational Flexibility (longitudinal) (mrad / daN.m)	Rotational Flexibility (circular) (mrad / daN.m)
Mark	Level (mm)	low (mm)	top (mm)			
I1	4,654.0	418.0	5,087.0	0.000398	0.003145	0.004198
O1	684.0	418.0	5,087.0	0.000398	0.014881	0.017812
O2	6,034.0	5,294.0	6,835.0	0.000353	0.000342	0.000539
I2	-1,426.0	/	/	0.000002	0.000036	0.000036

(*) the stiffening line may be a tangent line (head or skirt or cone) , a stiffener, a flange or a tubesheet which is the nearest

Circular stresses.

Type Mark		Diameter inside (mm)	Length (mm)	Thickness (mm)	Operation (MPa)	Horizontal test (MPa)	Vertical test (MPa)
01 KH	TS01	1,300.0	408.7	20.000	22.57	33.92	/
02 SH	TS02	1,300.0	151.0	16.000	29.42	44.22	/
03 EF	GF01						
04 EN	space						
05 TT	TT01						
06 SH	SS01	1,300.0	3,000.0	16.000	50.73	108.96	/
07 SH	SS01	1,300.0	1,669.0	16.000	50.73	108.96	/
08 TT	TT02						
09 EN	space						
10 EF	GF02						
11 SH	TS03	1,300.0	1,493.0	16.000	29.42	44.22	/
12 KH	TS04	1,300.0	393.1	16.000	29.42	44.22	/

Type : SH = Shell ; CT = Cone ; SK = Skirt ; TT = Tubesheet ; AF, BL, BF, CF, EF, DF ,WN, SO, EM, CL = Flange ;
EH, GH, KH, FH, HH,TH = Elliptical, GRC, Korboggen, Flat, Hemispherical, Torispherical Head ;
WE = Welding Elbow ; CH = Cap ; RE = Reducer.

Summary

Summary of nozzles [Location and Dimensions].

Tag	Location				Dimensions (mm)								Flange		
	Loc. (mm)	Ori. (°)	Inc. (°)	Ecc. (mm)	Neck Diam.	Th.	Sch.	DN	Reinforcement Type	(a)	(b)	Project.	NPS	Rating	Typ.
I1	4,654.0	0.00	0.00	0.00	273.00	12.500	/	250	Pad	16.000	174.00	254.00	10	300	WN
O1	684.0	180.00	0.00	0.00	168.30	11.000	/	150	Pad	16.000	86.00	204.00	6	300	WN
O2	6,034.0	270.00	0.00	0.00	813.00	16.000	/		Pad	16.000	234.00	539.00	34	150	WN
I2	-1,426.0	270.00	0.00	0.00	610.00	16.000	/	600	Pad	20.000	95.00	1,205.00	24	150	WN
V1	7,380.0	0.00	0.00	0.00	60.30	8.800	/	50	/	/	/	200.00	2	150	WN
T	300.0	0.00	0.00	0.00	84.00	16.600	/		L.W.N.	/	/	249.00	2	150	LN

Flange type: WN = welding neck (type 11 serie Pe), SO = slip-on (type 12 serie Pe), LN = long welding neck (type 21), PL = flat (type 01), EM = slip-on (type 12), CL = welding neck (type 11), TS/GM/GH = lap joint / clamped (glass lined vessel).

(a),(b) : Pad = thickness, width ; Self = height, over thickness ; Internal Plate = thickness, height

NB : The external projection and the height of over thickness of a self is measured on axis of the nozzle.

Summary of nozzles [Type, Adjacent Openings, Goose and Material].

Tag	Set-in Set-on	Type	Adjacent opening(s)	Goose Radius (mm)	Goose Loc. (mm)	Hydrostatic height Operation (mm)	Hydrostatic height Test (mm)	Material Neck	Material Pad	Material Flange
I1	in	CA	None	/	/	0.00	1,300.0	P355NL1	P355NL1	P355NH
O1	in	CS	None	/	/	0.00	1,300.0	P355NL1	P355NL1	P355NH
O2	in	TS	None	/	/	0.00	1,300.0	P355NL1	P355NL1	P355NH
I2	in	TA	None	914.00	1,426.0	0.00	1,300.0	P355NL1	P355NL1	P355NH
V1	in	E	None	/	/	0.00	1,300.0	P355NL1	/	P355NH
T	in	A	None	/	/	0.00	1,300.0	P355NH	/	P355NH

Nozzle type: A = process, H = manhole, E = with blind flange, L = instrument, AP = boot, XT = transition by head, CA = inlet shell, CS = outlet shell, TA = inlet channel, TS = outlet channel.

Summary of nozzles [Type, Weight and Local Loads].

Tag	Loc. Shell No.	Type	Weight Nozzle (daN)	Weight Flange (daN)	Longitudinal Shear Load (daN)	Circumferential Shear Load (daN)	Radial Load (daN)	Longitudinal Moment (daN.m)	Circular Moment (daN.m)	Torsional Moment (daN.m)
I1	07 SH	CA	62.8	41.0	0	0	1,105	1,560	3,058	0
O1	06 SH	CS	19.8	19.0	0	0	442	713	925	0
O2	11 SH	TS	342.8	211.0	0	0	10,630	13,000	100	0
I2	01 KH	TA	483.8	118.0	0	0	12,760	0	18,200	0
V1	12 KH	E	1.7	5.5	0	0	0	0	0	0
T	03 NO	A	6.8	2.4	0	0	0	0	0	0

Nozzle type: A = process, H = manhole, E = with blind flange, L = instrument, AP = boot, XT = transition by head, CA = inlet shell, CS = outlet shell, TA = inlet channel, TS = outlet channel.

Shell type: SH = Shell ; CT = Cone ; EH, GH, KH, FH, SH,TH = Elliptical, GRC, Korboggen, Flat, Hemispherical, Torispherical Head BL = Bolted cover ; FH = Flat Head ; NO = Nozzle.

Flange Weight: With blind flange if nozzle Type = E.

Summaries of bundle.

Baffles and Support Baffles.

Transverse :	No. = 8	Thk. = 13 mm	Diameter = 1,294 mm Total weight = 445.5 kg	Holes ϕ = 25.4 mm Material = P265GH
Locations (mm) : 947 + 7 × 500				

Support :	No. = /	Thk. = /	Diameter = / Total weight = /	Holes ϕ = / Material = /
Locations : /				

Longitudinal :	No. = /	Thk = /	Width = / Total weight = /	Total length = / Material = /
(location , length) : /				

Pass partition.

Front box	Total weight = /	Material = /
Rear box	Total weight = /	Material = /

Impingement plate, tubes by-pass and sealing strips.

Plate :	No. = /	Thk. = /	Length = /	Material = /
Tubes By-pass:	No. = /	Thk. = /	Diameter = /	Material = /
Sealing strips :	No. = 2	Thk.	Width	Material = CS
	1	20 mm	25 mm	
	2	20 mm	25 mm	

Sliding Rails.

Number = 2	Height / Diameter = 25 mm	Material = CS
Type = Bar	Width = 20 mm	

Tie Rods, spacers and Dummy Tubes.

Tie Rods :	Nb. = 9	Diameter = 12.7 mm	Total weight = 43.6 kg	Material = S235JRG2
Spacers :	Thk. = 2.11 mm	Diameter = 25 mm	Total weight = 52.3 kg	Material = S235JR
Dummy Tubes:	No. = /	Diameter = /	Total weight = /	Material = /

Miscellaneous.

/	No. = /	Thk. = /	Total weight = /	Material = /

Summary of tubes.

Total number of tubes = 1321	Tube thickness = 2.6 mm	Total weight = 9,253.3 kg
Tube length = 4,877 mm	Tube diameter = 25 mm	Total length = 6,442.5 m

Summary of Forged Items and Relevant Accessories.

Flange dimensions

Tag	Type (1)	(2)	Outside diameter (mm)	Inside diameter (mm)	Drilling circle (mm)	Flange thickness (mm)	Hub length (mm)	Cylindrical extension length (mm)	Hub thickness shellside (mm)	Hub thickness flangeside (mm)	Nubbins width (mm)	Stub thickness (mm)
GF01	C	1	1,502	1,300	1,430	72	37	0	16	24	0	0
GF02	C	1	1,502	1,300	1,430	72	37	0	16	24	0	0

(1) Flange type : P= slip-on (loose), C= integral with hub, T= lap-type joint (loose), R= slip-on (integral), G= clamped (integral), O= optional (corner joint), F= compression flange, S= backing flange.
(2) Flange face : 0= flat face unconfined, 1= male-female semi-confined, 2= tongue and groove, 3= tongue and groove + nubbins.

Bolting

Tag	(3)	No. [n_B]	Designation	Bolts Diameter (mm)	Stud bolts length (mm)	Bolt force [$F_{BO\ nom} / n_B$] (N)		Bolt torque [$M_{t,nom}$] (N.mm)	Friction coefficient in nut [μ_n]	Friction coefficient in thread [μ_t]	Thread pitch [p_t] (mm)
GF01	4	56	M20	20	205	26,117	**(4)**	84,384.13	0.12	0.12	2.5
GF02	4	56	M20	20	205	26,117	**(4)**	84,384.13	0.12	0.12	2.5

(3) Bolting type : 1,2,4,6 = ISO (1 et 4 : Pitch 3 mm for Ø > M24) (1 et 6 : Tensile Stress Area ; 2,4 : Root Area)
3 = UNC, Root Area
5 = ISO, Reduced Area (DIN 2510)

(4) Bolt torque according to EN 1591-1 Annex D : $M_{t,nom} = k_B \times F_{BO\ nom} / n_B$
$k_B = p_t/(2\pi) + \mu_t \times d_t/(2\cos\alpha) + \mu_n \times d_n/2$
d_t = pitch diameter of the thread
d_n = mean diameter in the nut (for the friction)
α = half angle of thread

(5) Bolt torque according to EN 13445-3 Annex G.8.4 :

Gaskets

Tag	Diameter (mm)	Width (mm	Thickness (mm)	Pass partition rib (mm)	Ring (mm) Outer Width	Inner Width	Thickness
GF01	1,351	19	4		0	0	0
GF02	1,351	19	4		0	0	0

Tubesheets

No.	Side	Recessed Face (mm)	Machining extension (mm)	Shell support or radius (mm)	Stress relief slope	But joint extension (mm)	Partition groove depth (mm)	Tube extension (mm)	External diameter (mm)	Thickness (mm)
1 **(a)**	Shell			10	0	14			1,502	80
	Tube	8	5							
2	Shell			10	0	14			1,502	80
	Tube	8	5							

(a) Floating tubesheet for a floating head exchanger

Summary of Geometry.

Type Mark		Diameter inside (mm)	Length (mm)	Height / base (mm)	Thickness (mm)	angle (°)	Weight (daN)	Flanges rating	Specific Gravity	Material
01 KH	TS01	1,300.0	408.7	60.0	20.000	0	339.7		7.85	P355NL1
02 SH	TS02	1,300.0	151.0	211.0	16.000	0	78.4		7.85	P355NL1
03 EF	GF01	1,300.0	109.0	320.0	0.000	0	260		7.85	P355NH
04 EN	*space*		*7.0*	*327.0*						
05 TT	TT01	1,502.0	91.0	418.0	0.000	0	695.5		7.85	P355NH
06 SH	SS01	1,300.0	3,000.0	3,418.0	16.000	0	1,557.8		7.85	P355NL1
07 SH	SS01	1,300.0	1,669.0	5,087.0	16.000	0	866.7		7.85	P355NL1
08 TT	TT02	1,502.0	91.0	5,178.0	0.000	0	695.5		7.85	P355NH
09 EN	*space*		*7.0*	*5,185.0*						
10 EF	GF02	1,300.0	109.0	5,294.0	0.000	0	260		7.85	P355NH
11 SH	TS03	1,300.0	1,493.0	6,787.0	16.000	0	775.3		7.85	P355NL1
12 KH	TS04	1,300.0	393.1	6,787.0	16.000	0	263.5		7.85	P355NL1

Type : SH = Shell ; CT = Cone ; SK = Skirt ; TT = Tubesheet ; WE = Welding Elbow ; CH = Cap ; RE = Reducer ;
AF, BL, BF, CF, EF, DF ,WN, SO, EM, CL = Flange ; JC = Jacket closure;
EH, GH, KH, FH, HH,TH = Elliptical, GRC, Korboggen, Flat, Hemispherical, Torispherical Head.

Angle : half angle at apex for a concentric cone ; maximum angle between cone an cylinder for an eccentric cone.

Material : (N) = normalized.

NB : Italic line indicates an element without pressure.

Summary of Weights, Capacities and Painting Areas.

Designation		Weight (daN)	Lifting	Erection	Operation	Test	Shut-down
Cylindrical shells		3,278	X	X	X	X	X
Cones							
Heads		603	X	X	X	X	X
Shell flanges		520	X	X	X	X	X
Skirts							
Supports		148	X	X	X	X	X
Anchor boxes							
Fire-proofing							
Man holes							
Nozzles		1,315	X	X	X	X	X
Piping							
Tray supports							
Trays							
Liquid on trays							
Packing							
Helicoidal plates							
Inner lining							
Insulation supports		71	X	X	X	X	X
Insulation		102			X		X
Coils							
Liquid in Coils							
Stiffeners							
Piping clips							
Structural clips							
Ladders							
Platforms							
Tubesheets		1,391	X	X	X	X	X
Tubes and tie rods		9,349	X	X	X	X	X
Baffles and support plates		446	X	X	X	X	X
Floating head flange							
Split ring							
Internals	Operation						
	Test						
	Lifting						
	Erection						
External loads	Operation						
	Test						
	Lifting						
	Erection						

	Compartment	Shell (comp. 1)	Tube (comp. 2)	/
Capacity (m³)		2.967	5.175	/
Hold-up Liquid (daN)	Operation	0	0	/
	Test	2,967	5,175	/
Test weight (daN)		/	/	/

Vessel weight (daN)	Operation	17,223
	Lifting	17,121
	Erection	17,121
	Shut-down	17,223

Painting Area (m²)	Vessel	34.9
	Support	1.6

NB : New weight.

Summary of Foundation Loads

Load Case	Vertical load (1) (daN)	Shear load (daN)	Bending Moment (daN.m)
Operation	17,223	0	0
Lifting	17,121	0	0
Erection	17,121	0	0
test	/	/	/
Shut-down	/	/	/

(1) non-corroded vessel weight

Definition of Brackets	
Number of brackets = 2	Number of ribs each bracket = 2
Number of bolts each bracket = 2	Bolt Circle Diameter = 1,826 mm
Bolt diameter = 24 mm	Distance between brackets = 2,868.27 mm

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Inlet Channel Lifting Lug

according to DIN 28086

Load

Empty Weight		W =	12500	N
Safety / impact factor (already included in lifting load)		s =	1.5	-
Total design load		Ftot =	18750	N
	(refer "Centre of gravity" calculation)			
Number of lifting lugs		n =	1	-
Maximum lifting angle (worst case)		ß =	60	°
Vertical load for one lug (radial)	Fy = Ftot/n =	Fy =	18750	N
Horizontal component (Longitudinal)	Fx = Fy*tanß	Fx =	32476.0	N
Design Load	Fe = Fy/cosß =	Fe =	37500.0	N

Material

Material Lug		P355NL1 EN 10028-3		
Yield stress at 20℃		Re(20) =	355.0	N/mm2
Tensile stress at 20℃		Rm(20) =	490.0	N/mm2
Maximum allowable stress	Sig all = Re / 1,5 =	**Sig all =**	**236.7**	**N/mm2**

Dimensions:

Width at top	L = 2*radius	L =	110	mm
Width at base		Lb =	110	mm
Height		h =	55	mm
Thickness		s1 =	10	mm
Hole diameter		d =	40	mm
Distance between lug parts	2C = (L+d)/2 =	2C =	75	mm
Width lug part	b =(L-d)/2 =	b =	35	mm

Stresses in lug at hole

Bending moment	M = (Fe*2C)/8 =	M =	351563	Nmm
Force	F1 = Fy/2 =	F1 =	9375.0	N
Modulus of cross section lug part	Z = s1*b^2/6	Z =	2042	mm3
Cross section area lug part	A = s1*b =	A =	350	mm2
Stress in lug at hole	S = M/Z+F1/A =	**S =**	**198.98**	**N/mm2**

Stresses in lug at base

Bending Moment	Mb = Fx*h =	Mb =	1786177	Nmm
Modulus of cross section at base	Zb = s1*Lb^2/6	Zb =	20167	mm3
Cross section area at base	Ab = s1*Lb =	Ab =	1100	mm2
Normal + Bending stresses	Snb = Mb/Zb + Fy/Ab =	Snb =	105.62	N/mm2
Shear stress	Taub =Fx/Ab =	Taub =	29.52	N/mm2
Total equivalent stress	Seb = sqrt(St2+Txz2)	**Seb =**	**109.67**	**N/mm2**

The calculation satisfies the requirements

Conclusion

This document contains checking of design of *Deisohexanizer Reboiler* (**E-610**), with the aim of assessing whether dimensions, materials, inspection and testing procedures, and other facts relevant to this heat exchanger, are in keeping with rules of construction of pressure vessels, additional rules pertaining to shell-and-tube type heat exchangers, applicable standards, relevant project specifications, and good engineering practice.

This analysis has affirmed that all parts of this shell-and-tube heat exchanger satisfy the design requirements pertinent to this project:

- Arbeitsgemeinschaft Druckbehälter AD 2000 Merkblätter, Ausgabe 11-2007
- EN-13445 Unfired pressure vessels, Part 3 Chapter 13 : Heat Exchanger Tubesheets (latest edition)
- Welding Research Council bulletin WRC-107, Local stresses in spherical and cylindrical shells due to external loadings, Edition 2002-10
- Standards Of The Tubular Exchanger Manufacturers Association (TEMA), Ninth Edition (2007)
- Lurgi Technical Specification for Pressure Vessels, Doc. №: 04962-SE-00003
- Lurgi Technical Specification for Heat Exchangers (Supplement to Technical Specification for Pressure Vessels), Doc. №: 04962-SE-00004
- Safety provisions of the Pressure Equipment Directive 97/23/EC (PED) of the EU

According to the specifications mentioned above, the guide drawing supplied by Lurgi (Doc. №: 04962-SE-00089) has been used as information in respect to minimum dimensions for this device.

Changes to dimensions contained in 04962-SE-00089 were made only when it was shown to be necessary:

- Dimensions of reinforcing pad on tube-side inlet nozzle I2 were changed from 1000×20 mm to 800×20 mm, in order to make the pad fall into the scope of WRC-107.

As per 04962-SE-00004 Chapter 2.9, the specific data regarding expansion bellows used for compensation of thermal expansion was also taken from the guide drawing 04962-SE-00089.

Since Note 12. of 04962-SE-00089 suggests that the evaluation of differential thermal expansion between tubes and shell should be done using the provided values of $T_{s,m}$ (mean metal temperature along shell length) and $T_{t,m}$ (mean metal temperature along tubes length), the calculation was performed for 4 specified cases (please see page 9 for the *Design case excluding Test* list).
The procedure has demonstrated that that the expansion joint is not necessary when these conditions are taken into account; consequently, this heat exchanger falls under the definition of '<u>Mean Metal Temperature Design</u>'.

As stated in Chapter 2.6.1 of 04962-SE-00004, lifting lug according to DIN 28086 has been provided for transport and erection of the inlet (bottom) channel (please also see page 145).