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et Préfabrication d'Arles

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Dossier CMP Arles : 783

Page/*Sheet* 0.1

Client / *Customer* **: MESSER** *Engineered System N°* **:**

1 RESERVOIR DE STOCKAGE LIN 1000MT

1 x 1000MT LIN STORAGE TANK

NOTE DE CALCUL MECANIQUE

MECHANICAL CALCULATION NOTE

1		28/07/04	HULIN	[signature]	28/07/04	CABRELLI	[signature]	28/07/04	LEBOUCQ	[signature]		
EDITION *EDITION N°*	REFERENCE *CLIENT REF.*	DATE	NOM *NAME*	SIGN.	DATE	NOM *NAME*	SIGN.	DATE	NOM *NAME*	SIGN.	ETAT D'AVANC. *STATUS*
		REDACTEUR *DRAWN UP BY*			VERIFICATEUR *CHECKED BY*			APPROBATEUR *APPROVED BY*			

Projet : *Project* ASU KOSICE

Classement CMP Arles : 783-NC102
CMP Arles document N°

Appareil / Item : 1 x 1000 MT LIN

Client : MESSER

Page	DESIGNATION *Desription*	INDICE DE REVISION *Revision number*								
		0	A	B	C	D	E	F	G	H
0.1	Page de garde / Front page	1								
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OBJET DES MODIFICATIONS :

(subject of modifications)

INDICE DE L'EDITION Edition n°	OBJET DE LA MODIFICATION (subject of modifications)
1	Premiere diffusion / First issue

DOCUMENTS DE REFERENCE

ET CONVENTIONS GENERALES

(Reference documents and generale conventions)

SPECIFICATION CLIENT :
Customer specification

PLAN CLIENT :
Customer drawing

PLAN CMP arles Drawing	783 - 101 783 - 102 783 - 103 783 - 104
CODE DE CALCUL : design code	API 620, edition 10, February 2002 (with App. Q) except inner shell against external pressure with AD MERKBLATT BO, B6
CONVENTIONS GENERALES : General conditions	S I system

1) GENERAL DATA :

Rep. Items	Description	Ep. Thk.	Corro -sion	Contrôle testing	Coef.joint joint effic.	Densité(kg/m3) density(kg/m3)	Matière Material
3	Inner vessel shell	5 to 6	0		1	8000	A 240-304
1& 2	Inner vessel roof	5	0		0.35	8000	A 240-304
6	Compression ring	15	0		/	8000	A 240-304
4	Inner vessel bottom	5 & 7	0		/	8000	A 240-304
5	Inner vessel stiffeners	/	0		/	8000	A 240-304
	Inner vessel piping	/	0	SEE	0.85	8000	A 312 TP-304L
12	Inner vessel anchorage	10	0	CRYO	/	8000	A 240-304
3	Outer casing shell	6	0	SPEC	0.7	8000	A283 gr C
1 & 2	Outer casing roof	6 & 10	0	25	0.35	8000	A283 gr C
5	Outer casing stiffeners	/	0		/	8000	EN10025 S235 JRG2
	Outer vessel piping	/	0		0.85	8000	A106GrB or EN10025 S235 JRG2
	Bolt anchorage for outer casing	M42	0		/		A193 B7 or A194 2H

2) GEOMETRIE DE L'APPAREIL :

(Geometry of equipment)

OUTER CASING

HOLD

2) GEOMETRIE DE L'APPAREIL :

(Geometry of equipment)

INNER VESSEL

HOLD

3) SOLLICITATIONS ;
solicitations

Items	sollicitations solicitations	Data Inner vesel	Outer casing
Tc	Temperature (°C)	20 -196	20
Dp	Internal pressure (MPa)	0.020	0.001
Pe	External pressure (MPa)	-0.001	/
Pps	Perlite compaction pressure for shell (MPa)	see p.17	0.0070
Ppr	Perlite compaction pressure for roof (MPa)	0.0007	/
Pv	Vacuum pressure (MPa)	-0.0005	-0.0005
Tp	Test pressure (MPa)	0.0250	0.00125
Ws	Wind velocity (N / m²)	/	1242
S	Snow (N /m²)	/	1373
dl	Specific gravity of the product (Kg/m³)	812	56
Hl	Service liquid height (mm)	16745	/

4) LOADING CASES :

Loading case	Concerned sollicitations	Conditions
A	Tc + dl.g.Hl + Dp + Pv(outer casing)	Internal vessel under internal pressure
B	Tc + 1000.g.Hl + Tp	Internal vessel under internal test pressure
C	Tc + Dp + Pps	Outer casing under internal pressure
E	Tc + (Pps or Ppr) + Pe + Pi(outer casing)	Internal vessel under external pressure
F	Tc + Ws + S + Pv	Outer casing under external pressure

Complementary verifications:

. For straps: 1,5 x max. burst pressure of 375 = 562.5mbar (without seismic) < 90% of yield strength
. For inner shell: max. burst pressure of 375mbar + liquid head < 90% of yield strength
. For inner roof: max. burst pressure of 375mbar < 90% of yield strength (the compression ring is only computed with 200 mbar)

5) ALLOWABLE STRESS :

MATERIAL : A 240-304 (**Inner vessel**)

Loading case	Temp. (°C)	Allowable stress Tensile	/ Compression	Origin of the stresses definition
A = DESIGN	-196	155.1 Mpa		see NOTE 1
B = TEST	20	186.1 Mpa		see NOTE 1

NOTE 1 : TENSILE : see API 620 App.Q Table Q3

MATERIAL : A283 gr C or equivalent (**Outer casing**)

Loading case	Temp. (°C)	Allowable stress Tensile	/ Compression	Origin of the stresses definition
C = DESIGN	20	104.8 Mpa		see NOTE 2

NOTE 2 : TENSILE : see API 620 Table 5.1 (15200 psi)

6) INNER VESSEL CALCULTION UNDER INTERNAL PRESSURE :

6.1) Inner vessel shell

According to API 620 section 5.10

API minimum thickness		Thk min =	4.76	mm
Joint efficiency (= 1 for test)		E =	1	
Inner vessel radius		Rc = Di / 2 =	4875	mm
Shell thickness		Thk =	in	mm
Shell and roof weight at each design level (design level = lower part of computed shell course)		Wm =	in	N
Liquid weight at each design level		WL =	in	N
Total weight	W = WL + Wm	W =	in	N
Hydrostatic pressure at each design level		PL =	in	Mpa
Internal pressure		Pg =	0.02	Mpa
Total pressure with gas pressure	P = PL + Pg	P =	in	Mpa
Unit force				
T1 = 0.5 x Rc x (P + (W / pi x Rc²))			in	N / mm
T2 = P x Rc			in	N / mm
Calculated stress	St = Max { T1 , T2 } / (E x Thk)			

With St allowable = 155.1 Mpa

1) **design conditions :**

Shell	Thk(mm)	Wm (N)	WL (N)	W (N)	PL (MPa)	P (Mpa)
3.1	6	-295930	-9958853	-10254777	0.1334	0.1534
3.2	6	-267138	-8772354	-9039487	0.1175	0.1375
3.3	5	-238346	-7585856	-7824197	0.1016	0.1216
3.4	5	-214355	-6399358	-6613708	0.0857	0.1057
3.5	5	-190364	-5212860	-5403219	0.0698	0.0898
3.6	5	-166373	-4026362	-4192730	0.0539	0.0739
3.7	5	-142382	-2839864	-2982241	0.0380	0.0580
3.8	5	-118391	-1653366	-1771752	0.0221	0.0421
3.9	5	-94400	-466868	-561262	0.0063	0.0263

Shell	Thk(mm)	T1 (N/mm)	T2 (N/mm)	St (MPa)	St allowable	ratio
3.1	6	39.1	747.757	124.6	155.1	1.2
3.2	6	40.0	670.285	111.7	155.1	1.4
3.3	5	41.0	592.813	118.6	155.1	1.3
3.4	5	41.8	515.342	103.1	155.1	1.5
3.5	5	42.5	437.870	87.6	155.1	1.8
3.6	5	43.3	360.399	72.1	155.1	2.2
3.7	5	44.1	282.927	56.6	155.1	2.7
3.8	5	44.9	205.455	41.1	155.1	3.8
3.9	5	45.7	127.984	25.6	155.1	6.1

We verify that the ratio is > 1

2) **Test conditions :**

We use water for the test calculation

water density = 1000 Kg / m^3 > liquide density= 812 Kg / m^3

See page 10 for test results.

2) **Test conditions :**

Shell	Thk(mm)	Wm (N)	WL (N)	W (N)	PL (MPa)	P (Mpa)
3.1	6	-295930	-12264597	-12560521	0.1643	0.1843
3.2	6	-267138	-10803392	-11070524	0.1447	0.1647
3.3	5	-238346	-9342188	-9580529	0.1251	0.1451
3.4	5	-214355	-7880983	-8095333	0.1056	0.1256
3.5	5	-190364	-6419778	-6610137	0.0860	0.1060
3.6	5	-166373	-4958574	-5124942	0.0664	0.0864
3.7	5	-142382	-3497369	-3639746	0.0468	0.0668
3.8	5	-118391	-2036165	-2154551	0.0273	0.0473
3.9	5	-94400	-574960	-669355	0.0077	0.0277

Shell	Thk(mm)	T1 (N/mm)	T2 (N/mm)	St (MPa)	St allowable	ratio
3.1	6	39.1	898.309	149.7	186.1	1.2
3.2	6	40.0	802.900	133.8	186.1	1.4
3.3	5	41.0	707.492	141.5	186.1	1.3
3.4	5	41.8	612.084	122.4	186.1	1.5
3.5	5	42.5	516.675	103.3	186.1	1.8
3.6	5	43.3	421.267	84.3	186.1	2.2
3.7	5	44.1	325.858	65.2	186.1	2.9
3.8	5	44.9	230.450	46.1	186.1	4.0
3.9	5	45.7	135.042	27.0	186.1	6.9

We verify that the ratio is > 1

6.2) Inner vessel roof calculation under internal pressure :

According to API 620 section 5.10

API minimum thickness	Thk min =	4.76	mm
Joint efficiency	J =	0.35	
Roof weight	Wm =	-32341	N
Accessories weight on roof	WA =	4905	N
Roof thickness	Thk =	5.00	mm
Inner shell radius	Rc =	4875	mm
Roof spherical radius	Rs =	9200	mm

1) design conditions :

Hydrostatic pressure	PL =	0	Mpa
Total pressure	P = PL + Pg =	0.02	Mpa
Total weight	W = Wm + WA =	-27436	N

Unit force

T1 = 0.5 x Rs x (P + W / (pi x Rc²)) = 91 N / mm

T2 = P x Rs - T1 = 93 N / mm

Calculated stress

S = Max { T1 , T2 } / (J x Thk) = 53.2 MPa < 155.1 MPa

2) Test conditions :

Hydrostatic pressure	PL =	0	Mpa
Total pressure	P = PL + Pg =	0.0250	Mpa
Total weight	W = Wm + WA =	-27436	N

Unit force

T1 = 0.5 x Rs x (P + W / (pi x Rc²)) = 114 N / mm

T2 = P x Rs - T1 = 116 N / mm

Calculated stress

S = Max { T1 , T2} / (J x Thk) = 66.3 MPa < 186.1 MPa

3) Vérification according AL rules :

max. burst pressure of 375 mbar = Pg

Hydrostatic pressure	PL =	0	Mpa
Total pressure	P = PL + Pg =	0.0375	Mpa
Total weight	W = Wm + WA =	-27436	N

Unit force

T1 = 0.5 x Rs x (P + W / (pi x Rc²)) = -171 N / mm

T2 = P x Rs - T1 = -174.2 N / mm

Calculated stress

S = Max { T1 , T2} / (J x Thk) = 99.6 MPa < 186.1 MPa

Inner vessel roof calculation under internal pressure

6.3) Roof to shell junction - compression ring :

Design according to API 620 section 5.12

Sketch of the compression area : See attached drawing p.14

Thk of the shell at the top = 5 mm

Permissible widths of plates making up the compression area :

$Wh = 0.6\,(Thk \times R)^{1/2}$ =	0.223	m
Where $Thk_{comp.\ ring}$ =	15.00	mm
$Wc = 0.6\,(Thk\ .Rc\ )^{1/2}$ =	0.093	
Where $Thk_{of\ shell}$ =	5.00	mm
$L < (16 \times Thk_{of\ comp.ring})$ =	0.24	m

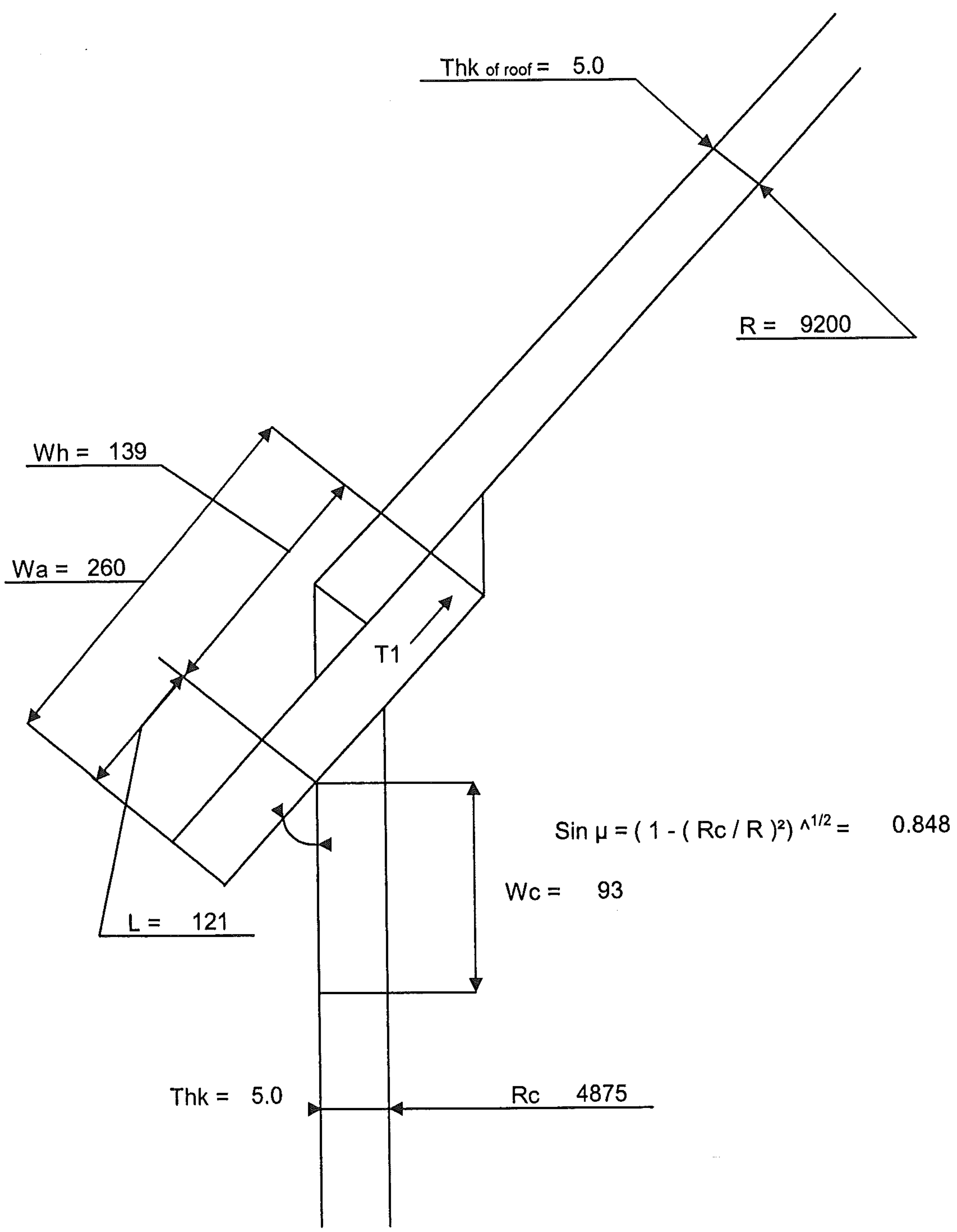
Actuel dimensions of the compression ring :

Wh =	139	mm
Wc =	93	mm
L =	121	mm

1) Under working conditions :

Gas design pressure	P=	20000	N /m²
Shell section	A =	74.7	m²
Proper mass of the roof	W =	32341	N
Roof meridional unit force :	T1 = R/2 x (P -W / A) =	90008	N / m
Roof circumferential unit force :	T2 = R x P - T1 =	93992	N / m
Shell circumferential unit force :	Tc = Rc x P =	97500	N / m

Roof to shell junction - compression ring :



Area of the interested compression zone:

$Sr = (L + Wh) \times Thk_{\text{of comp.ring}} + (Wc \times Thk_{\text{of shell}}) =$ 0.00437 m²

Circumferential forces action on the above section :

$Q = -T1 \times Rc \times \sin\mu + ((T2 \times Wh) + Tc \times Wc) =$ -349991.39 N

Where $\sin\mu = (1- (Rc/\ R)^2)^{1/2} =$ 0.848

Compression stress :

$n = - Q / Sr =$ 8.02E+07 N / m²

OK !

This computed stress is under the minimum acceptable value required by the API 620 code i.e. :15000 psi or 10.34E+7 N / m².

2) **Under testing conditions :**

gas design pressure :	P =	25000	N / m²
	T1 =	113008	N / m
	T2 =	116992	N / m
	Tc =	121875	N / m
	Q =	-440787	N
	n =	1.01E+08	N / m²

OK !

This computed stress is under the minimum acceptable value required by the API 620 code i.e. :15000 psi or 10.34E+7 N / m².

7) Inner vessel calculation under external pressure :

(with A.D. B0 & B6 Jan. 95 Ed.)

7.1) Inner vessel shell :

Data :

Design temperature :	T =	20	°C
Young's modulus :	E =	196000	MPa
Poisson's ratio :	v =	0.3	
Yield strenght at 1% :	K =	230	MPa
Safety factor against elastic buckling for shell :	Sk1 =	2.6	
Safety factor against elastic buckling for stiffener :	Sk2 =	3	
Safety factor against plastic strain :	S =	1.6	
Out of roundnessfactor :	u =	1.5	%

For Di, dp and the types of stiffeners : see "loads on storage tank supporting slab" p.2 & 3

the length between two stiffeners from down to up : (Z =),
the minimum of thickness of the shell : (Thk =),
and the type of the stiffener at the top of the space (A or B).

CASE N°	Z (mm)	Thk (mm)	Stiffeners type A or B
1	1840	6	A
2	1840	6	A
3	1350	5	A
4	1350	5	A
5	1350	5	A
6	1350	5	A
7	1350	5	A
8	1380	5	A
9	1600	5	A
10	1750	5	A
11	1890	5	0

External pressure data for inner vessel :

External pressure : Pc

Pc = Pe + Pv + Pps

where Pe : pressure in outer casing
Pv : negative pressure in inner vessel
Pps : perlite compaction pressure

-> External pressure at the top of the inner vessel : Pc= 26.0 mbar

-> Between the top and 7 m of shell
Calculation according to formula : Pc= Pc1+ (dp x 9.81/100) x H
Denstity Perlite : dp = 56 Kg/m3

-> After 7 m , Pc = Pc(H=7m) = 64.5 mbar

Safety calculation :

Elastic bluckling :

Calculation according to formula :

$$P1 = (E / Sk1) \times \{ [20 / ((n^2 - 1) \times [1 + (n / z)^2]] \times (Thk / Da) + 80 / (12 (1 - v^2)) \times [n^2 - 1 + (2n^2 - 1 - v) / (1 + (n / z)^2] \times (Thk / Da)^3 \} \times 1000$$

where :
Da = Di + 2 x Thk
z = 0.5 x (pi x Da / Z)
$n = 1.63 \times [Da^3 / (Z^2 \times Thk)]^{1/4}$
n : number of ridges which may appear on the circumference in case of bluckling

We verify : P1 > Pc

Plastic deformation :

Calculation according to formula :

if Da / Z < 5 :
P2 = (20 x K / S) x (Thk / Da) x [1 + [(1.5 x u x (1 - 0.2Da / Z) x Da) x Da) / (100 x Thk)]]

if Da / Z > 5 :
P2 = (20 x K / S) x (Thk / Da)

We verify : P2 > Pc

RESULTS :

Pc mbar , P1 mbar , ratio P1/Pc , P2 mbar , ratio P2/Pc

CASE N°	Pc (mbar)	P1(mbar)	P1/Pc	P2(mbar)	P2/Pc
1	64.5	107.96	1.7	1767.1	27.4
2	64.5	107.96	1.7	1767.1	27.4
3	64.5	95.55	1.5	1472.9	22.9
4	64.5	95.55	1.5	1472.9	22.9
5	64.5	95.55	1.5	1472.9	22.9
6	64.5	95.55	1.5	1472.9	22.9
7	64.5	95.55	1.5	1472.9	22.9
8	59.5	92.96	1.6	1472.9	24.8
9	52	78.63	1.6	1472.9	28.4
10	44.5	71.6	1.7	1472.9	33.1
11	35.7	66.31	1.9	1472.9	41.3

We verify : P1/Pc > 1 and P2/Pc > 1

Stiffeners calculation :

Calculation according to formula :

$$Pe = (240 \times E \times im) / [(1 - v^2) \times (Da - Thk) \times Dm^2 \times L]$$

$$X = [(P \times Lm \times Da) / (20 \times Am)] + [(P \times L \times Da^2) / (8000 \times Wm)] \times [u / (1 - (Sk2 \times P / Pe))]$$

$$Lm = 1.1 \times (Da \times Thk)^{1/2} + Thk\ W0$$

where im is the geometrical moment of inertia,
Dm : the relevant centre-of-gravity diameter,
Lm : the length of the supporting part of the shell,
Wm : the section modulus
L : the shell lenght for the calculation of the stiffeners

We verify :

$Pe > P \times Sk2$

$K / S > X$

$Iyy > (W1 + Thk\ W2)^4 / 3000$

where Iyy = the geometrical moment of inertia relative to the centre-of-gravity axis y-y

Calculation results in mm :

	W1	Thk W1	W2	Thk W2	Da	Thk	Dm	L
1	160	5	80	5	9762	6.0	9850	1840
2	160	5	80	5	9762	6.0	9850	1595
3	160	5	80	5	9760	5.0	9863	1350
4	160	5	80	5	9760	5.0	9863	1350
5	160	5	80	5	9760	5.0	9863	1350
6	160	5	80	5	9760	5.0	9863	1350
7	160	5	80	5	9760	5.0	9863	1365
8	160	5	80	5	9760	5.0	9863	1490
9	160	5	80	5	9760	5.0	9863	1675
10	160	5	80	5	9760	5.0	9863	1820

Results :

with the numerotation of the stiffeners from down to up

ratio 1 : 3000 x Iyy / (W1 + Thk W2)^4

N° stiffeners	Lm (mm)	Am (mm²)	Wm (mm^3)	im (mm^4)	Iyy (mm^4)	ratio 1
1	271	2827	98768	11960779	10190310	41
2	271	2827	98768	11960779	10190310	41
3	248	2440	96155	10904070	6570255	27
4	248	2440	96155	10904070	6570255	27
5	248	2440	96155	10904070	6570255	27
6	248	2440	96155	10904070	6570255	27
7	248	2440	96155	10904070	6570255	27
8	248	2440	96155	10904070	6570255	27
9	248	2440	96155	10904070	6570255	27
10	248	2440	96155	10904070	6570255	27

N° stiffeners	Pe (mbar)	P (mbar)	Pe / (P. Sk2)	X	K / S	ratio n° 2
1	355.0	64.5	1.8	55.6	143.8	2.6
2	409.5	64.5	2.1	52.1	143.8	2.8
3	440.0	64.5	2.3	51.2	143.8	2.8
4	440.0	64.5	2.3	51.2	143.8	2.8
5	440.0	64.5	2.3	51.2	143.8	2.8
6	440.0	64.5	2.3	51.2	143.8	2.8
7	435.1	59.5	2.4	47.7	143.8	3.0
8	398.6	52.0	2.6	43.5	143.8	3.3
9	354.6	44.5	2.7	39.4	143.8	3.7
10	326.3	35.7	3.0	33.8	143.8	4.3

We verify : ratio n°1 > 1 , Pe / (P.Sk2) > 1 , ratio n°2 > 1

7.2 / Inner vessel roof calculation under external pressure :

Vacuum pressure of the Inner tank :		P1 =	5	mbar
Internal pressure of the Outer tank :		P2 =	10	mbar
Hydrostatic head of the perlite :		P3 =	7.20	mbar
Weight of the roof :	P4 = 0.079 x 9.81 x Thk	P4 =	3.9	mbar
Design external pressure :	P = P1 + P2 + P3 + P4	P =	26.1	mbar
Roof Radius :		DRi =	9200	mm
Thickness :		Thk =	5.00	mm
Compressive stress :	St = (P x DRi) / 2Thk Scc = St x 145	St = Scc =	2.40 347.8	Mpa psi

According to **API 620 setion 5.5.4.3** the computed compressive stress, Scc, shall not exceed a value, Sca, established for the applicable thickness-to-radius ratio as follows :

If Thk / DRi < 0.00667 , Sca = 1 000 000 x Thk / DRi
If 0.00667 < Thk / DRi < 0.0175 , Sca = 5650 + 154.2 x Thk / DRi
If Thk / DRi > 0.0175 , Sca = 8340

Thk / DRi = 5.00 / 9200 = 0.00054 < 0.00667

So Sca = 1 000 000 x Thk / DRi = 543 psi

We verify : Scc < Sca -> OK !

8/ Inner vessel anchorage calculation :

1) Under design conditions :

Uplift force due to internal pressure

F = P x ((pi x D²) / 4) = 1493238 N

Weight of shell, shell stiffeners, bottom and roof of internal vessel (without perlite on roof)

W = 329594.08 N

Net uplift force

U = F - W = 1163644.2 N

Number of straps :	n =	32	
Strap section :	a =	1000	mm²
Uplift force per strap :	Ud = U / n =	36364	N

Tensile stress in Sd = Ud / a = 36.36 MPa < 155.1 MPa

OK !

2) AL Rules (1.5 x 375 = 562.5mbar / 90% yield strength)

F' = 4199732.6 N

U' = 3870138.5 N

Ud' = U' / n = 120942 N

Sd' = Ud' / a = 120.9 MPa < 186.1 MPa

OK !

NOTA : The test condition is covered by AL Rules (250mbar < 562,5mbar)

9/ Outer casing shell calculation under internal pressure :

9.1) Outer casing shell :

Design according to API 620 section 5.10

API minimum thickness		Thk min =	4.76	mm
Joint efficiency		J =	0.7	
Outer casing radius		Rc = Di / 2 =	6175	mm
Shell thickness		Thk =	6.00	mm
Shell and roof weight at each design level (design level = lower part of computed shell course)		Wm =	in	N
Accessories on roof + shell		WA =	in	N
Total weight	W = Wa + Wm	W =	in	N
Internal pressure		P =	in	Mpa
Unit force	T1 = 0.5 x Rc x (P + (W / pi x Rc²))	T1 =	in	N / mm
	T2 = P x Rc	T2 =	in	N / mm

St = Max { T1 , T2 } / (J x Thk)   Calculated stress

We verify the lower part of shell with : Thk = 6 mm

Wm =	-454257	N
WA =	-41202	N
W =	-495459	N
P =	0.008	MPa
T1 =	11.93	N / mm
T2 =	49.40	N / mm

St = 11.8 MPa < 104.8 MPa

OK !

9.2) Outer casing roof calculation under internal pression :

Design according to API 620 section 5.10

API minimum thickness	Thk min =	4.76	mm
Joint efficiency	J =	0.35	
Outer casing radius	Rc = Di / 2 =	6175	mm
Roof spherical radius	Rs =	10500	mm
Roof thickness	Thk =	6.00	mm
Roof weight	Wm =	-74938	N
Accessories weight on roof	WA =	-14715	N
Total weight	W =	Wa + Wm	
	W =	-89653	N
Internal pressure	P =	0.001	Mpa

Unit force

$T1 = 0.5 \times Rs \times (P + (W / pi \times Rc^2))$

T1 = 1.32 N / mm

$T2 = P \times Rs - T1$

T2 = 9.18 N / mm

Calculated stress

$St = Max \{ T1 , T2 \} / (J \times Thk)$

St = 4.4 MPa < 104.8 MPa

OK !

10/ Outer casing calculation under wind + negative gas pression :

10.1) Outer casing shell :

Wind load				q =	1242	N /m²
Depression max.	P2 =	0.005	bar	P2 =	500	N /m²
Negative pressure	P = q + P2			P =	1742	N /m²
Wind velocity equivalent	$V = ((2 \times P) / 1.23)^{1/2}$			V =	53.2	m /s
	$V_{miles/h} = V_{m/s} / 0.447$			V =	119.1	miles / h

Maximum allowable distance between stiffeners

According to API 620 section 5.10.6

$H = 6 \times (100 \times Thk) [100 / V]^2 \times [(100 \times Thk) / D]^{3/2}$

With :					
Thk =	6.00	mm	=	0.236	inch
D =	12350	mm	=	40.53	feet
V =	119.1	miles per hour			
H =	44.38	feet	=	13527	mm

Actual max. distance : H1max = 4500 mm = 14.8 feet

z = Required modulus of inertia of stiffener

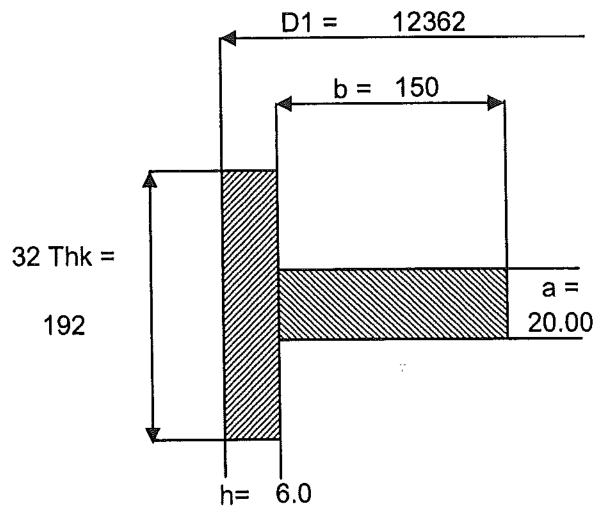
$z = 0.0001 \times D^2 \times H1max (V / 100)^2$

z = 3.45 cubic inch

z = 56525 mm^3

Actual modulus of inertia

= 110642 mm^3



10/ Outer casing calculation under wind + negative gas pression :

10.2) Outer casing roof calculation under external pressure :

Pressure due to the snow		Psn =	1373	N /m²
Pressure due to the wind		q =	1242	N /m²
Shape coefficient (pessimistic calc.)		cf =	1	
External loads	P1 = Psn + cf x q	with a minimum of 1200 N / m²		
		P1 =	2616	N /m²
Proper weight of the roof		Pr =	465	N /m²
Negative gas pressure		Pnp =	500	N /m²
Accessories weight	Pa = - Wa / (pi x Rc²)	Pa =	123	N /m²
Design pressure	P = P1 + Pr + Pnp + Pa	P =	3704	N /m²

Compressive stress in the roof

St = P x R / (2 x Thk x 1 000 000) with R = 10500 mm

St = 3.2 Mpa = 469.9 psi

According to API 620 section 3.5.3 , the above computed compressive stress does not exceed the value Scs.

Scs = 1000000 x Thk / R

Scs = 571 psi OK !

We verify : 571 psi > 469.90 psi

11/ Outer casing anchorage calculation :

Loading case : wind + internal pressure + gravity

Horizontal wind shear

F = cf x q x D x H

with :

Pressure on outercasing	q =	1242	N /m²
force coefficient (pessimistic calc.)	cf =	0.80	
Outer casing diameter	D =	12.362	m
Total height of tank (with accessories)	H =	21.542	m

F = 264665 N

Overturning moment M = F x H / 2

M = 2850661 Nm

Moment of inertia of the bolts set

I / V =N x S x R / 2

With :

N = Number of anchoring bolts =	12	
S = Sectional area of bolt =	1040	mm²
R = Radius of the bolt circle =	6075	mm

Load per bolt due to the wind moment

Q = M / (I / V) x S = 2 M / N.R

Q = 78207 N

Stress in the bolts due to wind only = Q / S = 75.2 MPa

Uplift due to the wind on the roof

$$U = cf \times q \times pi\, D^2 / 4$$

with

cf =	0.60	
q =	1242	N / m^2
D =	12.362	m
U =	89466	N

Uplift due to the internal pressure :

$L = 1.25\, p \times pi \times D^2 / 4$ =			150029.7	N
With p =	0.001	MPa =	1000	N / m^2
Dead weight of the outer casing W =			495459	N

Total maxi. load per bolt

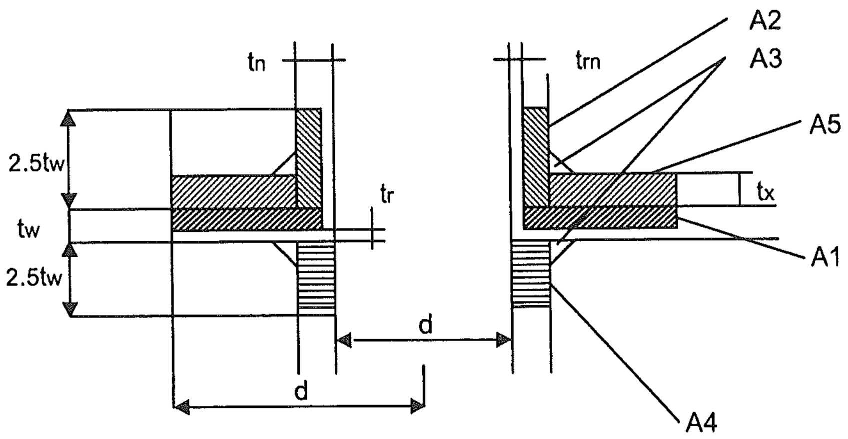
((U + L - W) / N) + Q =	56877	N

Stress in the bolts :

Maximum stress in the bolts :Smax =				165.5	MPa
56877	/	1040	=	54.7	MPa
			<	165.5	MPa

OK !

12/ Opening reinforcements for inner vessel nozzles :



trn = min. calculated thickness for nozzle

tr = min. calculated thickness for tank

A1 = (tw - tr) (d - 2 trn)

A2 = 2 (tn - trn) x 2.5 tw

A3 = welds are neglected

A4 = 2 tn x 2.5 tw

A5 = T x (d - 2 tn)

Total area available : Aa = A1 + A2 + A3 + A4 + A5

Required reinforcement area which is based on the piping resistance :

Internal pressure case Ar = (d.tr) / E x S plate / S piping with S = allowable stress

External pressure case Ar = (0.5 x d x tr) / E x S plate / S piping

Aa > Ar is verified.

NOZZLES

N° of the case	1	2	3	4
NOZZLE	K	G1 - G2	J	E1
Emplacement	Roof	Roof	Roof	Roof
Pressure	External	External	External	External
Nozzle Diam.	762	168.3	219.1	88.9
P (MPa)	0.00261	0.00261	0.00261	0.00261
R (mm)	9200	9200	9200	9200
tn (mm)	6	7.11	8.18	5.49
Nozzle elevation (mm)	-	-	-	-
reinforcement diam	1000	0	0	0
Tx (mm)	6	0	0	0
S plate (MPa)	155.1	155.1	155.1	155.1
tw (mm)	5	5	5	5
d (mm)	750	154.08	202.74	77.92
S piping (MPa)	155.1	129.1	129.1	129.1
trn (mm)	2	1.5	1.5	1
tr (mm)	4.1	4.1	4.10	4.1
A1 (mm^2)	675	136	180	68
A2 (mm^2)	100	140	167	112
A3 (mm^2)	0	0	0	0
A4 (mm^2)	150	178	205	137
A5 (mm^2)	1428	0	0	0
Aa (mm^2)	2353	454	551	318
E	1	1	1	1
Ar (mm^2)	1538	379	499	192
Aa / Ar	1.5	1.2	1.1	1.7
We verify :	Aa>Ar OK !	Aa>Ar OK !	Aa>Ar OK !	Aa>Ar OK !

A3 = 0 (welds are neglected)

VERIFICATION ACCORDING AL RULES

INNER VESSEL SHELL CALCULATION UNDER INTERNAL PRESSURE

(max. burst pressure = 375 mbar + hydrostatic head)

API minimum thickness		Thk min =	4.76	mm
Joint efficiency (= 1 for test)		E =	1	
Inner vessel radius		Rc = Di / 2 =	4875	mm
Shell thickness		Thk =	in	mm
Shell and roof weight at each design level (design level = lower part of computed shell course)		Wm =	in	N
Liquid weight at each design level		WL =	in	N
Total weight	W = WL + Wm	W =	in	N
Hydrostatic pressure at each design level		PL =	in	Mpa
Internal pressure		Pg =	0.0375	Mpa
Total pressure with gas pressure	P = PL + Pg	P =	in	Mpa
Unit force				
T1 = 0.5 x Rc x (P + (W / pi x Rc²))			in	N / mm
T2 = P x Rc			in	N / mm
Calculated stress	St = Max { T1 , T2 } / (E x Thk)			

With St allowable = 186.1 Mpa
(= 90% yield strength)

Shell	Thk(mm)	Wm (N)	WL (N)	W (N)	PL (MPa)	P (Mpa)
3.1	6	-295930	-9958853	-10254777	0.1334	0.1709
3.2	6	-267138	-8772354	-9039487	0.1175	0.1550
3.3	5	-238346	-7585856	-7824197	0.1016	0.1391
3.4	5	-214355	-6399358	-6613708	0.0857	0.1232
3.5	5	-190364	-5212860	-5403219	0.0698	0.1073
3.6	5	-166373	-4026362	-4192730	0.0539	0.0914
3.7	5	-142382	-2839864	-2982241	0.0380	0.0755
3.8	5	-118391	-1653366	-1771752	0.0221	0.0596
3.9	5	-94400	-466868	-561262	0.0063	0.0438

Shell	Thk(mm)	T1 (N/mm)	T2 (N/mm)	St (MPa)	St allowable	ratio
3.1	6	81.7	833.069	138.8	186.1	1.3
3.2	6	82.7	755.598	125.9	186.1	1.5
3.3	5	83.6	678.126	135.6	186.1	1.4
3.4	5	84.4	600.654	120.1	186.1	1.5
3.5	5	85.2	523.183	104.6	186.1	1.8
3.6	5	86.0	445.711	89.1	186.1	2.1
3.7	5	86.8	368.240	73.6	186.1	2.5
3.8	5	87.5	290.768	58.2	186.1	3.2
3.9	5	88.3	213.296	42.7	186.1	4.4

We verify that the ratio is > 1