GOST Calculation for steam generator

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CALCULATION REPORT

GOST Calculation for steam generator

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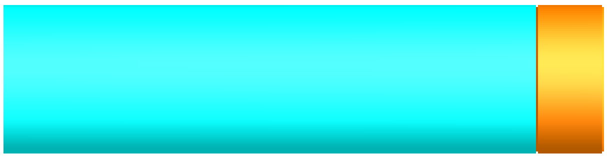
TABLE OF CONTENTS

1 General

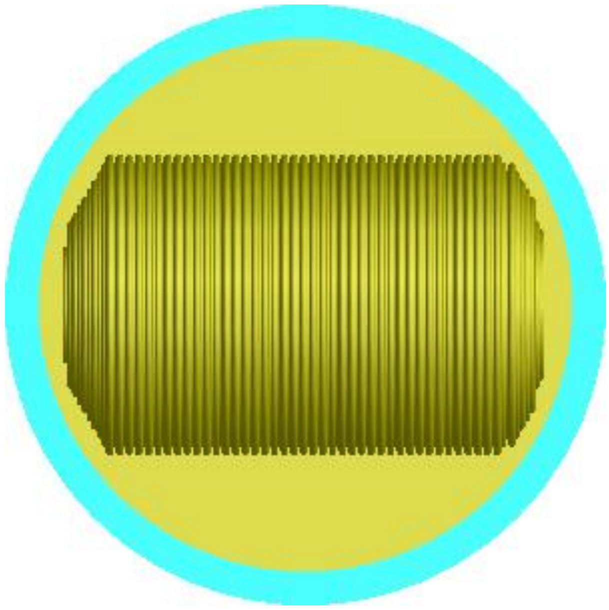
Strength calculation is provided using «PASS/EQUIP 3.03.0.9» program, designed by OOO NTP «Truboprovod».

2 General calculation data

Vessel overview

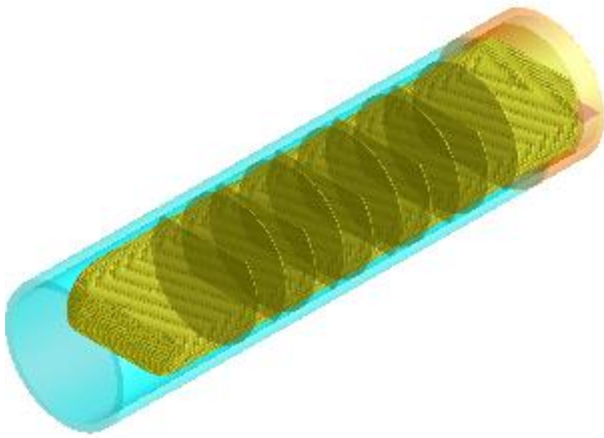


Top view



Left view

Front view



Isometric view

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3 Summary tables

3.1 Basic components

Table 3.1.Input data

Component	Material	Diameter, mm	Wall thickness, mm	Length (height), mm	Total allowance, mm	Weld strength ratio
Heat exchanger shell	SA-516 Gr.70 Plate	1750	110	7111	3	1
Tubes	SA-213 Gr.T11 Smls. tube	25.4	2.77	–	0	–
Tubesheet	SA-336 Gr.F22 Forgings	–	390	–	3	–

Table 3.2.Operating conditions (INTERNAL)

Component	Calculation temperature, °C	Calculation pressure, MPa	Allowable stresses, MPa	Effective thickness including allowances, mm	Allowable pressure, MPa	Strength condition
Heat exchanger shell	343	14.134	129.79	103.77	14.957	satisfied

Table 3.3.Operating conditions (EXTERNAL)

Component	Calculation temperature, °C	Calculation pressure, MPa	Allowable stresses, MPa	Effective thickness including allowances, mm	Allowable pressure, MPa	Strength condition
Heat exchanger shell	200	(-0.103)	150	13.086	15.883	satisfied

Table 3.4.Test conditions

Component	Calculation pressure, MPa	Allowable stresses, MPa	Effective thickness including allowances, mm	Allowable pressure, MPa	Strength condition
Heat exchanger shell	22.017	238.18	84.803	28.172	satisfied

3.2 Filling calculation

Table 3.5.Operating conditions (INTERNAL)

Component	Full volume, m³	Product volume, m³	Product mass, kg	Height of product column, mm	Max. height of product column at 100%, mm	ξ
Main shell Bundle	Tube-side: 5.0678	5.0678	4054.2	1366.4	1366.4	1
	Shell-side:14.125	14.125	11300	1750	1750	1
∑	19.192	19.192	15354	–	–	–

Table 3.6.Operating conditions (EXTERNAL)

Component	Full volume, m³	Product volume, m³	Product mass, kg	Height of product column, mm	Max. height of product column at 100%, mm	ξ
Main shell Bundle	Tube-side: 5.0678	5.0678	0	1366.4	1366.4	1
	Shell-side:14.125	14.125	0	1750	1750	1
∑	19.192	19.192	0	–	–	–

3.3 Vessel volumes

ρ – fluid density
V_{full}– full volume
V_{fluid} – fluid volume
M – fluid mass

Table 3.7.Volumes filling

Component	Testing	P_{test}, MPa	Fluid	ρ, kg/m³	V_{full}, m³	V_{fluid}, m³	M, kg	Fluid	H_2S
Main shell Bundle	Hydro	22	Yes	800	5.0678	5.0678	4054.2	water	No (–)
Heat exchanger shell	Hydro	22	Yes	800	14.125	14.125	11300	water	No (–)

Table 3.8.Volumes filling

Component	Testing	P_{test}, MPa	Fluid	ρ, kg/m³	V_{full}, m³	V_{fluid}, m³	M, kg	Fluid	H_2S
Main shell Bundle	Hydro	22	Yes	0	5.0678	5.0678	0		No (–)
Heat exchanger shell	Hydro	22	Yes	0	14.125	14.125	0		No (–)

3.4 Calculation of weights and centers of gravity

Table 3.9.Operating conditions (INTERNAL) (with the filling environment)

Component	Weight, N	The center of gravity position (relative to the model origin)
Main shell Bundle	$8.6559 \cdot 10^5$	X = 0 mm, Y = 0mm, Z = 3586.2 mm
$\sum$	$8.6559 \cdot 10^5$	X = 0 mm, Y = 0mm, Z = 3586.2 mm

Table 3.10.Operating conditions (EXTERNAL) (with the filling environment)

Component	Weight, N	The center of gravity position (relative to the model origin)
Main shell Bundle	$6.8652 \cdot 10^5$	X = 0 mm, Y = 0mm, Z = 3676.7 mm
$\sum$	$6.8652 \cdot 10^5$	X = 0 mm, Y = 0mm, Z = 3676.7 mm

Table 3.11.Test conditions (with the filling environment)**When the pneumatic test, or for the empty component, or for the absence of the testing, dry weight is appears

Component	Weight, N	The center of gravity position (relative to the model origin)
Main shell Bundle	$8.9597 \cdot 10^5$	X = 0 mm, Y = 0mm, Z = 3606.4 mm
$\sum$	$8.9597 \cdot 10^5$	X = 0 mm, Y = 0mm, Z = 3606.4 mm

Table 3.12.Mounting conditions (dry weight)

Component	Weight, N	The center of gravity position (relative to the model origin)
Main shell Bundle	$6.8652 \cdot 10^5$	X = 0 mm, Y = 0mm, Z = 3676.7 mm
$\sum$	$6.8652 \cdot 10^5$	X = 0 mm, Y = 0mm, Z = 3676.7 mm

3.5 Materials using

Table 3.13.Components materials

Component	Material	Quantity	Surface area (inside+outside)
Main shell Bundle			
	SA-213 Gr.T11 Smls. tube	23340 kg	2085.9 m²
	SA-336 Gr.F22 Forgings	4158.3 kg	56.026 m²
	SA-387 Gr.22 Plate	89.849 kg	1.0282 m²
	SA-516 Gr.70 Plate	42415 kg	138.23 m²
In total:			
	SA-213 Gr.T11 Smls. tube	23340 kg	2085.9 m²
	SA-336 Gr.F22 Forgings	4158.3 kg	56.026 m²
	SA-387 Gr.22 Plate	89.849 kg	1.0282 m²
	SA-516 Gr.70 Plate	42415 kg	138.23 m²

3.6 Testing pressure calculation as per GOST 34347, hydro

Table 3.14.Pressure values by components (INTERNAL)

Component	Testing pressure, MPa
Main shell Bundle	25.931
	$P_{test,min}$ = 25.931
Main shell Bundle	21.992
Heat exchanger shell	23.759
	$P_{test,min}$ = 21.992

Table 3.15.Pressure values by components (EXTERNAL)

Component	Testing pressure, MPa
Main shell Bundle	0.12879
	$P_{test,min}$ = 0.12879
Main shell Bundle	0.11853
Heat exchanger shell	0.11853
	$P_{test,min}$ = 0.11853

Table 3.16.Equipment category as per CU TR 032/2013

Assigned component	Only liquid inside (ξ>0.99)	Operating fluid group	Capacity, m^3	The product of the maximum allowable operating pressure and capacity, $MPa{\cdot}m^3$	Maximum allowable operating pressure, MPa	Equipment category
Main shell Bundle	Yes	II	5.0678	84.433	16.661	1
Heat exchanger shell	Yes	II	14.125	199.63	14.134	1

Note: in accordance with claim 2, 3 CU TR 032/2013 the category of equipment intended for use with design temperature above the beginning creep temperature of the material is increased by 1 (except category 4). The beginning creep temperature is:
400°C - for carbon and low-alloy Si-Mn steel;
450°C - for low-alloy Cr-Mo and Mo-V steels;
525°C - for alloyed high-chromium martensitic and austenitic steels;
575°C - for Fe-Ni and nickel-based alloys.

3.7 MDMT

Required MDMT: -36 °C

Table 3.17.Operating conditions (INTERNAL)

Component name	Code	Material	Curve	Governing thickness, mm	MDMT, °C	R_{ts} ratio	MDMT reduction, °C	Note

Table 3.18.Operating conditions (EXTERNAL)

Component name	Code	Material	Curve	Governing thickness, mm	MDMT, °C	R_{ts} ratio	MDMT reduction, °C	Note

4 Drawings of forces and moments

4.1 Calculation of wind loads as per GOST 34283-2017 (RUS)

Wind load applied to the i-th section:

$$P_{wi} = 1.8 \cdot q_0 \cdot \theta_i \cdot D_i \cdot h_i$$

where q_0 – regulatory value of wind pressure;
D_i – outside diameter of the i-th section;
h_i – length of the i-th section;
θ_i – coefficient, considering wind pressure changing throughout the vessel height:

$$\theta_i = \left(\frac{y_i + y_{осн}}{10}\right)^{0.3}$$

where y_i – distance from foundation to gravity centre of the i-th section.

Calculation in operating conditions (INTERNAL)

The model is not fixed

Calculation in operating conditions (EXTERNAL)

The model is not fixed

Calculation in test conditions (Hydrotesting conditions)

The model is not fixed

5 Heat exchanger shell

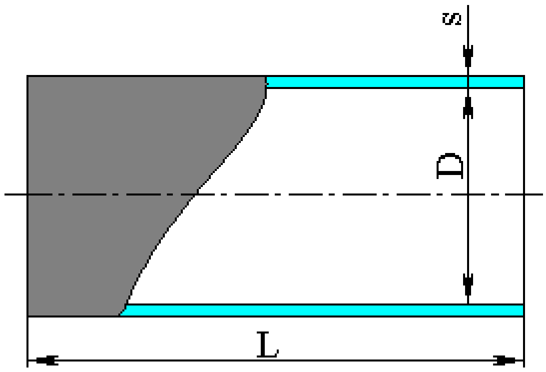

Fig.5.1.Component sketch

5.2 Input data

Material:	SA-516 Gr.70 Plate
Inside diameter,D:	1750 mm
Nominal thickness, s:	110 mm
Corrosion and erosion allowance, c_1:	3 mm
Negative tolerance, c_2:	0 mm
Technological allowance, c_3:	0 mm
Total allowance to the effective nominal thickness, c:	3 mm
Shell length, L:	7111 mm

Weld strength ratios:

Longitudinal weld: φ_p	1
Circular weld: φ_T	1

Loading conditions:

Calculation temperature, T:	343 °C
Calculation internal overpressure, p:	14.134 MPa
Calculation bending moment, M:	0 N·m
Calculation transverse force, Q:	0 N
Calculation axial tensile force, F:	0 N

Calculation of strength and buckling as per GOST 34233.2-2017

Allowable stresses for material SA-516 Gr.70 Plate at a temperature of 343 °C (operating conditions):

$$[\sigma] = \min\left(\frac{R_{e/t}}{n_T}; \frac{R_{m/t}}{n_B}\right) = \min\{194.68 / 1.5 ; 483 / 2.4\} = 129.79 \text{ MPa}$$

Module of longitudinal elasticity at a temperature of T = 343 °C:

E= $1.7984 \cdot 10^5$ MPa

Slick shells loaded with internal overpressure

Effective nominal thickness including allowances:

$$s_p + c = \frac{p \cdot D}{2 \cdot [\sigma] \cdot \varphi_p - p} + c \quad = (14.134 * 1750) / (2 * 129.79 * 1 - 14.134) + 3 \quad = 103.77 \text{ mm}$$

103.77 mm ≤ 110 mm

Conclusion: **Condition of operability is satisfied.**

Allowable pressure:

$$[p] = \frac{2 \cdot [\sigma] \cdot \varphi_p \cdot (s - c)}{D + (s - c)} \quad = \quad 2 * 129.79 * 1 * (110 - 3) / (1750 + 110 - 3) \quad = 14.957 \text{ MPa}$$

14.957 MPa ≥ 14.134 MPa

Conclusion: **Condition of strength is satisfied.**

Minimum distance between “single” nozzles:

$$b_0 = 2 \cdot \sqrt{D \cdot (s - c)} \quad = 2 * (1750 * (110 - 3))^{1/2} \quad = 865.45 \text{mm}$$

Testing pressure calculation as per GOST 34347, hydro

Tube side:

Hydraulic test pressure, when the component is under internal pressure, GOST 34347-2017:

$$P_{пр} = 1.25 \cdot p \cdot \frac{[\sigma]_{20}}{[\sigma]_t} - p_H$$ *=1.25 * 16.661 * 174.67 / 125.47 – 0.013401* = 28.979 MPa

Hydraulic test pressure, when the component is under internal pressure, GOST 34347-2017:

$$P_{пр} = 1.25 \cdot p \cdot \frac{[\sigma]_{20}}{[\sigma]_t} - p_H$$ *=1.25 * 16.661 * 206.67 / 165.89 – 0.013401* = 25.931 MPa

Shell side:

Hydraulic test pressure, when the component is under internal pressure, GOST 34347-2017:

$$P_{пр} = 1.25 \cdot p \cdot \frac{[\sigma]_{20}}{[\sigma]_t} - p_H$$ *=1.25 * 14.134 * 174.67 / 125.47 – 0.017162* = 24.578 MPa

Hydraulic test pressure, when the component is under internal pressure, GOST 34347-2017:

$$P_{пр} = 1.25 \cdot p \cdot \frac{[\sigma]_{20}}{[\sigma]_t} - p_H$$ *=1.25 * 14.134 * 206.67 / 165.89 – 0.017162* = 21.992 MPa

Hydraulic test pressure, when the component is under internal pressure, GOST 34347-2017:

$$P_{пр} = 1.25 \cdot p \cdot \frac{[\sigma]_{20}}{[\sigma]_t} - p_H$$ *=1.25 * 14.134 * 174.67 / 129.79 – 0.017162* = 23.759 MPa

Loading conditions:

Calculation temperature, T:	200 °C
Calculation external overpressure, p:	0.103 MPa
Calculation bending moment, M:	0 N·m
Calculation transverse force, Q:	0 N
Calculation axial tensile force, F:	0 N

Calculation of strength and buckling as per GOST 34347, hydro

Allowable stresses for material SA-516 Gr.70 Plate at a temperature of 200 °C (operating conditions):

$$[\sigma] = \min\left(\frac{R_{e/t}}{n_T}; \frac{R_{m/t}}{n_B}\right)$$ *=min{225 / 1.5 ; 483 / 2.4}*= 150 MPa

Module of longitudinal elasticity at a temperature of T = 200 °C:

E= $1.92 \cdot 10^5$ MPa

A slick shell loaded with external pressure

Effective length for calculation of pressure influence:

l_p = 7111 mm

$$B = \max\left\{1; 0.47 \cdot \left(\frac{p}{10^{-5} \cdot E}\right)^{0.067} \cdot \left(\frac{l}{D}\right)^{0.4}\right\}$$ *=max{1; 0.47 * (0.103 / (10^-5 * 1.92·10^5))^0.067 * (7111 / 1750)^0.4}* = 1

Effective shell nominal thickness including allowances:

$$s_p + c = \max\left\{1.06 \cdot \frac{10^{-2} \cdot D}{B} \cdot \left(\frac{p}{10^{-5} \cdot E} \cdot \frac{l}{D}\right)^{0.4}; \frac{1.2 \cdot p \cdot D}{2 \cdot [\sigma] - p}\right\}$$ *=max{1.06 * 10^-2 * 1750 / 1 * (0.103 /(10^-5 * 1.92·10^5) * 7111 / 1750)^0.4; 1.2 * 0.103 * 1750 / (2 *150 – 0.103)} + 3* = 13.086mm

13.086 mm ≤ 110 mm

Conclusion: **Condition of operability is satisfied.**

$$B_1 = \min\left\{1.0; 9.45 \cdot \frac{D}{l} \cdot \sqrt{\frac{D}{100 \cdot (s-c)}}\right\}$$ = *min{1.0; 9.45 * 1750 / 7111* (1750 / (100 * (110 – 3)))^1/2}* =0.94052

Allowable external pressure from buckling condition:

$$[p]_E = \frac{2.08 \cdot 10^{-5} E}{n_y \cdot B_1} \cdot \frac{D}{l} \cdot \left[\frac{100 \cdot (s-c)}{D}\right]^{2.5}$$ = *2.08 * 10^-5 * 1.92·10^5 * 1750 / (2.4 * 0.94052* 7111) * (100 * (110 – 3) / 1750)^2.5* =40.249MPa

Allowable external pressure from strength condition:

$$[p]_П = \frac{2 \cdot [\sigma] \cdot (s-c)}{D + (s-c)}$$ = *2 * 150 * (110 – 3) / (1750 + 110 – 3)* =17.286MPa

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						10

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$$[p] = \frac{[p]_{\Pi}}{\sqrt{1+\left(\frac{[p]_{\Pi}}{[p]_{E}}\right)^2}}$$ = *17.286 / (1 + (17.286 / 40.249)²)^1/2* =15.883MPa

15.883 MPa ≥ 0.103 MPa

Conclusion: **Condition of strength and buckling is satisfied.**

Minimum distance between “single” nozzles:

$$b_0 = 2\cdot\sqrt{D\cdot(s-c)}$$ = *2 * (1750 * (110 – 3))^1/2* = 865.45mm

A shell working under a combined action of loads

A shell working under a combined action of external pressure, compressing axial force, bending moment and transverse force.

Buckling condition testing $$\left(\frac{p}{[p]}+\frac{F}{[F]}+\frac{M}{[M]}+\left(\frac{Q}{[Q]}\right)^2\le 1\right)$$

$$\frac{p}{[p]}+\frac{F}{[F]}+\frac{M}{[M]}+\left(\frac{Q}{[Q]}\right)^2$$ = *0.103 / 15.883 + 0 / 0 +0 / 0 + (0 / 0)²* = 0.0064849 ≤ 1

Conclusion: **Condition of buckling is satisfied.**

Testing pressure calculation as per GOST 34347, hydro

Tube side:

Hydraulic test pressure, when the component is under vacuum (design pressure is taken equal to 0.1 MPa in the test pressure calculation), GOST 34347-2017:

$$P_{пр} = 1.25\cdot p\cdot\min\left\{\frac{[\sigma]_{20}}{[\sigma]_t};\frac{E_{20}}{E_t}\right\}-p_H$$ *=1.25 * 0.10197 *min{174.67/125.47;2.0235·10⁵/1.758·10⁵ }–0.013401* = 0.13331 MPa

Hydraulic test pressure, when the component is under vacuum (design pressure is taken equal to 0.1 MPa in the test pressure calculation), GOST 34347-2017:

$$P_{пр} = 1.25\cdot p\cdot\min\left\{\frac{[\sigma]_{20}}{[\sigma]_t};\frac{E_{20}}{E_t}\right\}-p_H$$ *=1.25 * 0.10197 *min{206.67/165.89;2.1035·10⁵/1.8856·10⁵ }–0.013401* = 0.12879 MPa

Shell side:

Hydraulic test pressure, when the component is under external pressure, GOST 34347-2017:

$$P_{пр} = 1.25\cdot p\cdot\min\left\{\frac{[\sigma]_{20}}{[\sigma]_t};\frac{E_{20}}{E_t}\right\}-p_H$$ *=1.25 * 0.103 *min{174.67/125.47;2.0235·10⁵/1.758·10⁵ }–0.017162* = 0.13103 MPa

Hydraulic test pressure, when the component is under external pressure, GOST 34347-2017:

$$P_{пр} = 1.25\cdot p\cdot\min\left\{\frac{[\sigma]_{20}}{[\sigma]_t};\frac{E_{20}}{E_t}\right\}-p_H$$ *=1.25 * 0.103 *min{206.67/165.89;2.1035·10⁵/1.8856·10⁵ }–0.017162* = 0.12647 MPa

Hydraulic test pressure, when the component is under external pressure, GOST 34347-2017:

$$P_{пр} = 1.25\cdot p\cdot\min\left\{\frac{[\sigma]_{20}}{[\sigma]_t};\frac{E_{20}}{E_t}\right\}-p_H$$ *=1.25 * 0.103 *min{174.67/150;2.0235·10⁵/1.92·10⁵ }–0.017162* = 0.11853 MPa

5.3 Calculation in test conditions (Hydrotesting conditions)

Loading conditions for tests:

Calculation temperature, T:	20 °C
Calculation internal overpressure (including hydrostatic), p:	22.017 MPa
Calculation bending moment, M:	0 N·m
Calculation transverse force, Q:	0 N
Calculation axial tensile force, F:	0 N

As per GOST 34233.1-2017, strength calculation in test conditions was not made, if the following condition is satisfied:

$$P_{исп} < 1.35\cdot P_{расч}\cdot\frac{[\sigma]_{20}}{[\sigma]}$$

$$1.35\cdot P_{расч}\cdot\frac{[\sigma]_{20}}{[\sigma]}$$ *=1.35 * 14.134 *174.67 / 129.79* = 25.679 MPa ≥ 22.017 MPa

Calculation of strength and buckling as per GOST 34347, hydro

Allowable stresses for material SA-516 Gr.70 Plate at a temperature of 20 °C (hydrotesting conditions):

$[\sigma]^{20} = \frac{R_{e/t}}{n_T}$ *=262 / 1.1=* 238.18 MPa

Module of longitudinal elasticity at a temperature of T = 20 °C:

$E^{20} =$ 2.0235·10^5 MPa

Slick shells loaded with internal overpressure

Effective nominal thickness including allowances:

$$s_p + c = \frac{p \cdot D}{2 \cdot [\sigma] \cdot \varphi_p - p} + c$$ *= (22.017 * 1750) / (2 * 238.18 * 1 – 22.017) + 0* =84.803 mm

84.803 mm ≤ 110 mm

Conclusion: **Condition of operability is satisfied.**

Allowable pressure:

$$[p] = \frac{2 \cdot [\sigma] \cdot \varphi_p \cdot (s - c)}{D + (s - c)}$$ = *2 * 238.18 * 1 * (110 – 0) / (1750 + 110 -0)* =28.172 MPa

28.172 MPa ≥ 22.017 MPa

Conclusion: **Condition of strength is satisfied.**

Minimum distance between “single” nozzles:

$$b_0 = 2 \cdot \sqrt{D \cdot (s - c)}$$ *= 2 * (1750 * (110 – 0))$^{1/2}$* = 877.5mm

6 Tubesheet

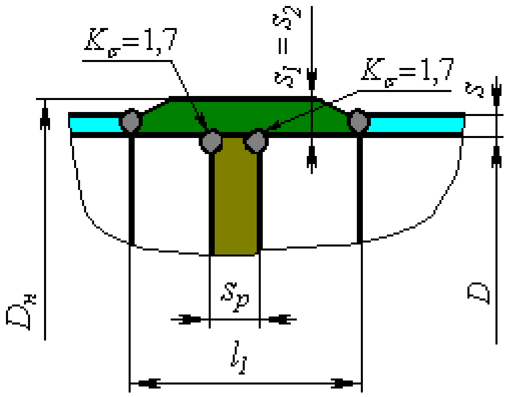

Fig.6.2.Connection sketch

6.2 Input data

Tubesheet:

Material:	SA-336 Gr.F22 Forgings
Thickness, s_{-p}:	390 mm
Total allowance to the calculated sheet thickness, c_p:	3 mm
Availability of separation wall:	Yes
Sheet thickness in a place of groove, s_n:	380 mm
Groove width, b_n:	11 mm

Transitional shell:

Material:	SA-516 Gr.70 Plate
Diameter, D:	1750 mm
Thickness, s_1:	110 mm
Corrosion allowance, c_1:	3 mm
Negative tolerance, c_2:	0mm
Technological allowance, c_3:	0mm
Total allowance, c:	3 mm
Length, l_1:	900 mm

Separation wall

Material:	SA-387
Thickness, s_{nep}:	25 mm
Total allowance, c_n:	3 mm
Width, b_{nep}:	1750 mm
Length, L_{nep}:	265 mm

Tubes layout

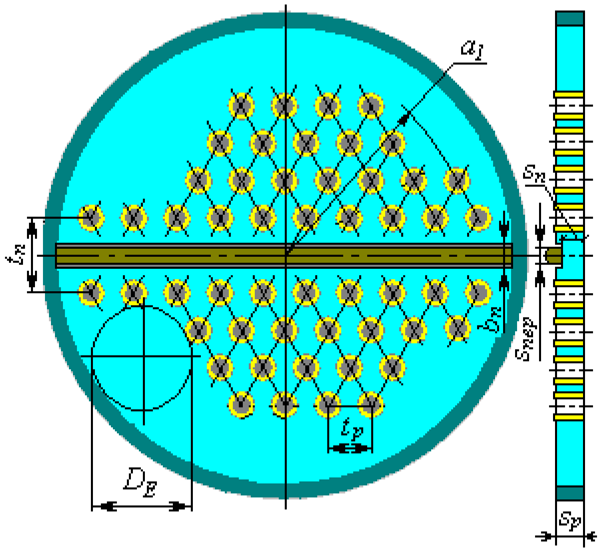

Fig.6.3.Tube bundle sketch

Maximum radius of tube zone:	828.65 mm
Holes interval, t_p:	31.75 mm
Hole diameter, d_0:	25.65 mm
Height of upper segment of tube zone, h_1:	715 mm
Height of lower segment of tube zone, h_2:	715 mm
Distance between rows of holes, t_n	76.2 mm

Tubes

Material:	SA-213 Gr.T11 Smls. tube
Outside diameter, d_T:	25.4 mm
Nominal thickness, s_T:	2.77 mm
Total allowance, c_T:	0 mm
Number of tubes in tubesheet, i:	2304
Design length of tubes, L_T:	6200 mm
Number of holes, n	2304
Distance from the shell axis to the axis of the furthermost tube, a_1	815.84 mm
Diameter of the circle inscribed in maximum tubeless area, D_E	381.25 mm

6.3 Calculation in operating conditions (INTERNAL)

Loading conditions:

Tube-side overpressure, p_T: 16.661 MPa
Shell-side overpressure, p_M: 14.134 MPa
Calculation temperature, T_p: 343 °C

Calculation of strength and buckling as per GOST 34233.7-2017

tube material properties:

Module of longitudinal elasticity at a temperature of T = 370 °C:
$E= 1.814 \cdot 10^5$ MPa
Thermal expansion at a temperature of T = 370 °C:
$\alpha= 0.1368 \cdot 10^{-4}$ 1/°C

Shell material properties:

Module of longitudinal elasticity at a temperature of T = 343 °C:
$E= 1.7984 \cdot 10^5$ MPa
Thermal expansion at a temperature of T = 343 °C:
$\alpha= 0.13544 \cdot 10^{-4}$ 1/°C

Tubesheet material properties:

Module of longitudinal elasticity at a temperature of T = 343 °C:
$E_p= 1.8856 \cdot 10^5$ MPa

Joint materials properties:

Shell flange material properties:

Minimum length of transitional shell:

$[l_1] = 2 \cdot \sqrt{D \cdot s_1}$ = $2 * (1750 * 110)^{1/2}$ = 877.5 mm

Length condition of transitional shell: $l_1 \geq [l_1]$

900 mm ≥ 877.5 mm.

Module of longitudinal elasticity at a temperature of T = 370 °C:

E_{f1}= $1.758 \cdot 10^5$ MPa

Chamber flange material properties:

Module of longitudinal elasticity at a temperature of T = 370 °C:

E_{f2}= $1.758 \cdot 10^5$ MPa

Shell material properties:

Module of longitudinal elasticity at a temperature of T = 343 °C:

E_1= $1.7984 \cdot 10^5$ MPa

Chamber material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:

E^{20}_2= $2.0235 \cdot 10^5$ MPa

Sheet material properties:

Allowable stresses for material SA-336 Gr.F22 Forgings at a temperature of 343 °C (operating conditions):

$[\sigma]_p = \min\left(\frac{R_{e/t}}{n_T}; \frac{R_{m/t}}{n_B}\right)$ = *min{248.84 / 1.5 ; 488.12 / 2.4}*= 165.89 MPa

Tubesheet strength

Calculated pressure (is taken equal to maximum possible difference of pressures influencing the tubesheet):

$p_R = \max\{|p_T|; |p_M|; |p_T - p_M|\}$ = *max{ |16.661|; |14.134|; |16.661 – 14.134|}* =16.661 MPa

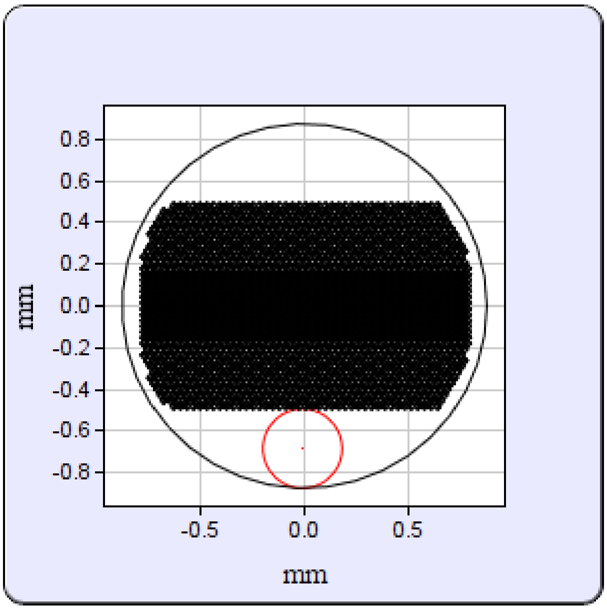

Fig.6.4.Tubes layout sketch

Calculated sheet thickness in the tubeless zone:

$s_{pp} = 0.5 D_E \sqrt{\frac{p_R}{[\sigma]_p}}$ = $0.5 * 381.25 * (16.661 / 165.89)^{1/2}$ =60.41 mm

Strength condition: $s_p \geq s_{pp} + c_p$

390 mm ≥ 60.41 +3 = 63.41 mm.Condition of strength is satisfied.

For tubesheets with tubes fixed along full width of the tubesheet:

$d_E = d_0 - 2s_T$ = *25.65 – 2 * 2.77* =20.11 mm

Effective reduction factor:

$\varphi_E = 1 - \frac{d_E}{t_p}$ = *1 – 20.11 / 31.75* =0.36661

Calculated tubesheet thickness in the perforation zone:

$$s_p^P = \frac{D_{cп}}{3.4} \cdot \sqrt{\frac{p_R}{\varphi_E \cdot [\sigma]_p}} \quad = \quad 1750 / 3.4 * (16.661 / (0.36661 * 165.89))^{1/2} \quad = 269.39 \text{ mm}$$

Strength condition: $s_p \ge s_p^P + c_p$

390 mm ≥ 269.39 +3 = 272.39 mm.Condition of strength is satisfied.

Calculated tubesheet thickness from the strength condition in the groove section:

$$s_{пp} = s_p^P \max\left\{\left[1 - \sqrt{\frac{d_0}{b_п}\left(\frac{t_п}{t_p} - 1\right)}\right];\ \sqrt{\varphi_E}\right\} \quad = \quad 269.39 * \max\{[1 - (25.65 / 11 * (76.2 / 31.75 - 1))^{1/2}; 0.36661^{1/2}\} \quad = 163.11 \text{ mm}$$

Strength condition: $s_п \ge s_{пp} + c_p$

380 mm ≥ 163.11 +3 = 166.11 mm.Condition of strength is satisfied.

6.4 Calculation in operating conditions (EXTERNAL)

Loading conditions:

Tube-side overpressure, p_T: $(-1 \cdot 10^{-4})$ MPa
Shell-side overpressure, p_M: (-0.103) MPa
Calculation temperature, T_p: 200 °C

Calculation of strength and buckling as per GOST 34233.7-2017

tube material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:
E^{20}= $2.043 \cdot 10^5$ MPa
Thermal expansion at a temperature of T = 20 °C:
α^{20}= $0.115 \cdot 10^{-4}$ 1/°C

Shell material properties:

Module of longitudinal elasticity at a temperature of T = 200 °C:
E= $1.92 \cdot 10^5$ MPa
Thermal expansion at a temperature of T = 200 °C:
α= $0.127 \cdot 10^{-4}$ 1/°C

Tubesheet material properties:

Module of longitudinal elasticity at a temperature of T = 200 °C:
E_p= $1.99 \cdot 10^5$ MPa

Joint materials properties:

Shell flange material properties:

Minimum length of transitional shell:

$$[l_1] = 2 \cdot \sqrt{D \cdot s_1} \quad = \quad 2 * (1750 * 110)^{1/2} \quad = 877.5 \text{ mm}$$

Length condition of transitional shell: $l_1 \ge [l_1]$

900 mm ≥ 877.5 mm.

Module of longitudinal elasticity at a temperature of T = 20 °C:
E^{20}_{f1}= $2.0235 \cdot 10^5$ MPa

Chamber flange material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:
E^{20}_{f2}= $2.0235 \cdot 10^5$ MPa

Shell material properties:

Module of longitudinal elasticity at a temperature of T = 200 °C:
E_1= $1.92 \cdot 10^5$ MPa

Chamber material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:
E^{20}_2= $2.0235 \cdot 10^5$ MPa

Sheet material properties:

Allowable stresses for material SA-336 Gr.F22 Forgings at a temperature of 200 °C (operating conditions):

$$[\sigma]_p = \min\left(\frac{R_{e/t}}{n_T}; \frac{R_{m/t}}{n_B}\right) = \min\{263 / 1.5 ; 498 / 2.4\} = 175.33 \text{ MPa}$$

Tubesheet strength

Calculated pressure (is taken equal to maximum possible difference of pressures influencing the tubesheet):

$$p_R = \max\{|p_T|;|p_M|;|p_T - p_M|\} \quad = \quad \max\{ |(-1\cdot10^{-4})|; |(-0.103)|; |(-1\cdot10^{-4}) - (-0.103)|\} \quad =0.103 \text{ MPa}$$

Diameter of the circle inscribed in maximum tubeless area, D_E 381.25 mm

Calculated sheet thickness in the tubeless zone:

$$s_{pp} = 0.5 D_E \sqrt{\frac{p_R}{[\sigma]_p}} \quad = \quad 0.5 * 381.25 * (0.103 / 175.33)^{1/2} \quad =4.6202 \text{ mm}$$

Strength condition: $s_p \geq s_{pp} + c_p$

390 mm ≥ 4.6202 +3 = 7.6202 mm.Condition of strength is satisfied.

For tubesheets with tubes fixed along full width of the tubesheet:

$$d_E = d_0 - 2s_T \quad = \quad 25.65 - 2 * 2.77 \quad =20.11 \text{ mm}$$

Effective reduction factor:

$$\varphi_E = 1 - \frac{d_E}{t_p} \quad = \quad 1 - 20.11 / 31.75 \quad =0.36661$$

Calculated tubesheet thickness in the perforation zone:

$$s_p^p = \frac{D_{cn}}{3.4} \cdot \sqrt{\frac{p_R}{\varphi_E \cdot [\sigma]_p}} \quad = \quad 1750 / 3.4* (0.103 /(0.36661 * 175.33))^{1/2} \quad =20.603 \text{ mm}$$

Strength condition: $s_p \geq s_p^p + c_p$

390 mm ≥ 20.603 +3 = 23.603 mm.Condition of strength is satisfied.

Calculated tubesheet thickness from the strength condition in the groove section:

$$s_{np} = s_p^p \max\left\{\left[1 - \sqrt{\frac{d_0}{b_n}\left(\frac{t_n}{t_p} - 1\right)}\right]; \sqrt{\varphi_E}\right\} \quad = \quad 20.603 * \max\{[1 - (25.65 / 11 * (76.2 / 31.75 - 1))^{1/2};0.36661^{1/2}\} \quad =12.475 \text{ mm}$$

Strength condition: $s_n \geq s_{np} + c_p$

380 mm ≥ 12.475 +3 = 15.475 mm.Condition of strength is satisfied.

6.5 Calculation in test conditions (Hydrotesting conditions)

Loading conditions for tests:

Tube-side overpressure, p_T: 22.013 MPa
Shell-side overpressure, p_M: 22.017 MPa
Calculation temperature, T_p: 20 °C

Calculation of strength and buckling as per GOST 34233.7-2017

tube material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:
E^{20}= $2.043\cdot10^5$ MPa
Thermal expansion at a temperature of T = 20 °C:
α^{20}= $0.115\cdot10^{-4}$1/°C

Shell material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:
E^{20}= $2.0235\cdot10^5$ MPa
Thermal expansion at a temperature of T = 20 °C:
α^{20}= $0.115\cdot10^{-4}$1/°C

Tubesheet material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:
$E^{20}{}_p$= $2.1035\cdot10^5$ MPa

Joint materials properties:

Shell flange material properties:

Minimum length of transitional shell:

$$[l_1] = 2 \cdot \sqrt{D \cdot s_1} \quad = \quad 2 * (1750 * 110)^{1/2} \quad = 877.5 \text{ mm}$$

Length condition of transitional shell: $l_1 \geq [l_1]$

900 mm ≥ 877.5 mm.

Module of longitudinal elasticity at a temperature of T = 20 °C:

E^{20}_{f1}= 2.0235·10^5 MPa

Chamber flange material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:

E^{20}_{f2}= 2.0235·10^5 MPa

Shell material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:

E^{20}_{1}= 2.0235·10^5 MPa

Chamber material properties:

Module of longitudinal elasticity at a temperature of T = 20 °C:

E^{20}_{2}= 2.0235·10^5 MPa

Sheet material properties:

Allowable stresses for material SA-336 Gr.F22 Forgings at a temperature of 20 °C (hydrotesting conditions):

$[\sigma]^{20}_p = \frac{R_{e/t}}{n_T}$ *=310 / 1.1=* 281.82 MPa

Tubesheet strength

Calculated pressure (is taken equal to maximum possible difference of pressures influencing the tubesheet):

$p_R = \max\{|p_T|; |p_M|; |p_T - p_M|\}$ = *max{ |22.013|; |22.017|; |22.013 – 22.017|}* =22.017 MPa

Calculated sheet thickness in the tubeless zone:

$$s_{pp} = 0.5 D_E \sqrt{\frac{p_R}{[\sigma]_p}}$$ = *0.5 * 381.25 * (22.017 / 281.82)$^{1/2}$* =53.281 mm

Strength condition: $s_p \geq s_{pp} + c_p$

390 mm ≥ 53.281 +0 = 53.281 mm.Condition of strength is satisfied.

For tubesheets with tubes fixed along full width of the tubesheet:

$d_E = d_0 - 2s_T$ = *25.65 – 2 * 2.77* =20.11 mm

Effective reduction factor:

$$\varphi_E = 1 - \frac{d_E}{t_p}$$ = *1 – 20.11 / 31.75* =0.36661

Calculated tubesheet thickness in the perforation zone:

$$s_p^p = \frac{D_{cn}}{3.4} \cdot \sqrt{\frac{p_R}{\varphi_E \cdot [\sigma]_p}}$$ = *1750 / 3.4* (22.017 /(0.36661 * 281.82))$^{1/2}$* =237.6 mm

Strength condition: $s_p \geq s_p^p + c_p$

390 mm ≥ 237.6 +0 = 237.6 mm.Condition of strength is satisfied.

Calculated tubesheet thickness from the strength condition in the groove section:

$$s_{np} = s_p^p \max\left\{\left[1 - \sqrt{\frac{d_0}{b_n}\left(\frac{t_n}{t_p} - 1\right)}\right]; \sqrt{\varphi_E}\right\}$$ = *237.6 * max{[1 – (25.65 / 11 * (76.2 / 31.75 – 1))$^{1/2}$;0.36661$^{1/2}$}* =143.87 mm

Strength condition: $s_n \geq s_{np} + c_p$

380 mm ≥ 143.87 +0 = 143.87 mm.Condition of strength is satisfied.

7 Separation wall

7.1 Calculation in operating conditions (INTERNAL)

Loading conditions:

Calculation temperature, T:	343 °C
Differential pressure, Δp:	0.5 MPa

Calculation of strength and buckling as per GOST 34233.7-2017

Allowable stresses for material SA-387 Gr.22 Plate at a temperature of 343 °C (operating conditions):

$$[\sigma]_n = \min\left(\frac{R_{e/t}}{n_T};\frac{R_{m/t}}{n_B}\right)$$ =*min{248.84 / 1.5 ; 488.12 / 2.4}*= 165.89 MPa

$$f_n = \frac{1}{1+\frac{b_{пер}}{L_{пер}}+\left(\frac{b_{пер}}{L_{пер}}\right)^2}$$ = *1 / (1 + 1750 / 265 + (1750 / 265)²)* =0.019526

Design thickness of separation wall :

$$s^P_{пер} = 0.71\,b_{пер}\sqrt{\frac{\Delta p f_n}{[\sigma]_n}}$$ = *0.71 * 1750 * (0.5 * 0.019526 / 165.89)^(1/2)* =9.5318 mm

Strength condition: $s_{пер} \geq s^P_{пер} + c_n$

25 mm ≥ 9.5318 +3 = 12.532 mm.Condition is satisfied.

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8 Tubes

8.1 Calculation in operating conditions (INTERNAL)

Loading conditions:

Axial force influencing the tube, N_T: 5161.1 N

Bending moment influencing the tube, M_T: 0 N·m

Calculated pressure (is taken equal to maximum possible difference of pressures influencing the tubesheet):

$$p_R = \max\{|p_T|; |p_M|; |p_T - p_M|\} \quad = \quad \max\{\ |16.661|;\ |14.134|;\ |16.661 - 14.134|\} \quad = 16.661 \text{ MPa}$$

Tubes material properties:

Allowable stresses for material SA-213 Gr.T11 Smls. tube at a temperature of 370 °C (operating conditions):

$$[\sigma]_T = \min\left(\frac{R_{e/t}}{n_T};\ \frac{R_{m/t}}{n_B}\right) = \min\{155.6 / 1.5\ ;\ 414 / 2.4\} = 103.73 \text{ MPa}$$

Module of longitudinal elasticity at a temperature of T = 370 °C:

E= $1.814 \cdot 10^5$ MPa

Calculated stresses in tubes

Axial membrane stresses:

$$\sigma_{mT} = \frac{|N_T|}{\pi \cdot (d_T - s_T) \cdot (s_T - c_T)} \quad = \quad |5161.1| / (3.1416 * (25.4 - 2.77) * (2.77 - 0)) \quad = 26.208 \text{ MPa}$$

Circumferential stresses:

$$\sigma_{\theta T} = \frac{(d_T - s_T) p_R}{2 \cdot (s_T - c_T)} \quad = \quad (25.4 - 2.77) * 16.661 / (2 * (2.77 - 0)) \quad = 68.056 \text{ MPa}$$

Strength of tubes

Static strength condition of tubes: $\max\{\sigma_{mT}; \sigma_{\theta T}\} \le [\sigma]_T$

max{26.208; 68.056} MPa ≤ 103.73 MPa.Condition of strength is satisfied.

8.2 Calculation in operating conditions (EXTERNAL)

Loading conditions:

Axial force influencing the tube, N_T: (-0.030978) N

Bending moment influencing the tube, M_T: 0 N·m

Calculated pressure (is taken equal to maximum possible difference of pressures influencing the tubesheet):

$$p_R = \max\{|p_T|; |p_M|; |p_T - p_M|\} \quad = \quad \max\{\ |(-1 \cdot 10^{-4})|;\ |(-0.103)|;\ |(-1 \cdot 10^{-4}) - (-0.103)|\} \quad = 0.103 \text{ MPa}$$

Tubes material properties:

Allowable stresses for material SA-213 Gr.T11 Smls. tube at a temperature of 20 °C (operating conditions):

$$[\sigma]^{20}_T = \min\left(\frac{R_{e/t}}{n_T};\ \frac{R_{m/t}}{n_B}\right) = \min\{207 / 1.5\ ;\ 414 / 2.4\} = 138 \text{ MPa}$$

Module of longitudinal elasticity at a temperature of T = 20 °C:

E^{20}= $2.043 \cdot 10^5$ MPa

Calculated stresses in tubes

Axial membrane stresses:

$$\sigma_{mT} = \frac{|N_T|}{\pi \cdot (d_T - s_T) \cdot (s_T - c_T)} \quad = \quad |(-0.030978)| / (3.1416 * (25.4 - 2.77) * (2.77 - 0)) \quad = 0.1573 \cdot 10^{-3} \text{ MPa}$$

Circumferential stresses:

$$\sigma_{\theta T} = \frac{(d_T - s_T) p_R}{2 \cdot (s_T - c_T)} \quad = \quad (25.4 - 2.77) * 0.103 / (2 * (2.77 - 0)) \quad = 0.42074 \text{ MPa}$$

Strength of tubes

Static strength condition of tubes: $\max\{\sigma_{mT}; \sigma_{\theta T}\} \le [\sigma]_T$

max{$0.1573 \cdot 10^{-3}$; 0.42074} MPa≤ 138 MPa.Condition of strength is satisfied.

8.3 Calculation in test conditions

Loading conditions for tests:

Axial force influencing the tube, N_T: 6819.2 N

Bending moment influencing the tube, M_T: 0 N·m

Calculated pressure (is taken equal to maximum possible difference of pressures influencing the tubesheet):

$p_R = \max\{|p_T|; |p_M|; |p_T - p_M|\}$ = *max{ |22.013|; |22.017|; |22.013 – 22.017|}* =22.017 MPa

Tubes material properties:

Allowable stresses for material SA-213 Gr.T11 Smls. tube at a temperature of 20 °C (hydrotesting conditions):

$[\sigma]^{20}_T = \frac{R_{e/t}}{n_T}$ *=207 / 1.1*= 188.18 MPa

Module of longitudinal elasticity at a temperature of T = 20 °C:

E^{20}= $2.043 \cdot 10^5$ MPa

Calculated stresses in tubes

Axial membrane stresses:

$\sigma_{mT} = \frac{|N_T|}{\pi \cdot (d_T - s_T) \cdot (s_T - c_T)}$ = *|6819.2| / (3.1416 * (25.4 – 2.77) * (2.77 – 0))* =34.628 MPa

Circumferential stresses:

$\sigma_{\theta T} = \frac{(d_T - s_T) p_R}{2 \cdot (s_T - c_T)}$ = *(25.4 – 2.77) * 22.017 / (2 * (2.77 – 0))* =89.937 MPa

Strength of tubes

Static strength condition of tubes: $\max\{\sigma_{mT}; \sigma_{\theta T}\} \le [\sigma]_T$

max{34.628; 89.937} MPa ≤ 188.18 MPa.Condition of strength is satisfied.

9 References

1) GOST 34233.1-2017. Vessels and apparatus. Norms and methods of strength calculation. General requirements.
2) GOST 34233.2-2017. Vessels and apparatus. Norms and methods of strength calculation. Calculation of cylindric and conic, shells convex and flat bottoms and covers.
3) GOST 34233.7-2017. Vessels and apparatus. Norms and methods of strength calculation. Heat exchangers.
4) GOST 34283-2017. Vessels and apparatus. Norms and methods of strength calculation from wind loads, seismic influence and other external loads.
5) GOST 34347-2017. Steel welded vessels and apparatus. General specifications

1

2 Sheet of changes registration

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						24