Stress in the tank case at mounting displacements and loads on nozzles

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Abstract. In the practice of operating capacitive equipment, production moments often arise due to technical re-equipment and changes in the operating parameters of tanks to meet specific requirements for equipment design in the technological process. Common reconstruction activities involve modifying process nozzles in technical device housings to align with process piping project specifications. Consequently, the stressed-deformed state in vessel bodies before and after reconstruction can vary significantly. During manufacturing or repair tasks, permissible installation displacements, such as the shifting of edges in joined cylindrical shell housings, may occur within regulatory limits. This study focuses on analyzing stress variations and stress distribution zones, considering the combined effects of these factors.

1 Introduction

Process vessels refer to shell structures widely used at oil and gas facilities. In the course of operation, the influence of force factors in the shells causes the formation and distribution of acting stresses of different values, both in value and in direction. Studies in the field of studying the laws and features of the distribution of the stress-strain state (SSS) in shell structures are devoted to work [1-4].

SPD distribution in capacitive equipment housings is always of an individual nature, which can depend on various parameters, such as, for example: defective level, operating loads, design features, number and location of process nozzles, presence of installation deviations and many others. Each of them makes a certain contribution to the quantitative assessment of stresses, as well as the formation of zones of their concentration [5-8].

During the reconstruction of process tanks, as well as during their repair, these parameters can take on a complex nature and to a decisive extent affect the SSS. For example, a complex effect on the SSS in the housings of capacitive equipment can have a combination of factors such as the tapping of new nozzles, changes in operating parameters, as well as the displacement of the edges of the joined elements in annular welds. With their complex impact, the formation of SPD in the vessel housings may be rather ambiguous, which must be taken into account when assigning a further service life and ensuring operational reliability [9-10].

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Therefore, the actual work is the study of the nature of the formation of values and zones of increased stresses in the housings of capacitive equipment depending on the scope and type of technical re-equipment work, as well as the presence of installation displacements in circular welds.

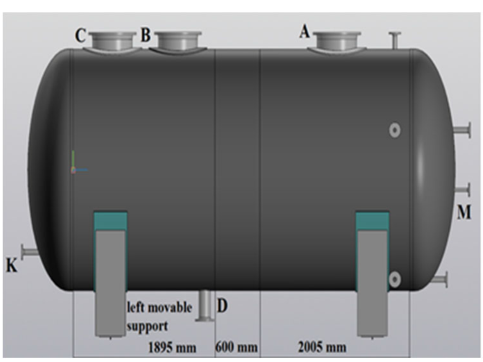
2 Research methodology

The object of the study was the process horizontal tank, which was subjected to technical re-equipment (re-cutting of process nozzles and changing process parameters).

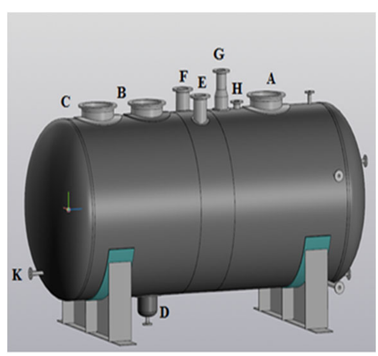
Before the reconstruction, the process parameters of the tank are as follows: internal overpressure equal to 0,1MPa and temperature equal to plus 200 °C. After reconstruction for the needs of the technological process, the internal overpressure was increased to 0.6 MPa, and the temperature was reduced to 30 °C. The vessel is a cylindrical welded apparatus consisting of three shells welded to each other, with lengths of 2005 mm, 600 mm and 1895 mm, respectively. There are two elliptical bottoms. The tank is equipped with the required number of process nozzles. The material of the cylindrical shell of the housing, bottoms and nozzles is low-alloy 09G2S steel. Reservoir is installed on two saddle supports, left of which is movable, and right support is fixed fixedly. The thickness of the cylindrical shell is 14 mm, and the wall thickness of the bottoms is 18 mm. Nozzles have the following nominal diameters in millimeters:

- connectors A, B, CDN500;
- connector D (before reconstruction) DN150;
- connector M DN25;
- other DN50 connectors.

During the reconstruction, new nozzles F, E DN200, H DN100, GDN200/150, DDN50 were welded. Instead of nozzle D, which was the nominal diameter of the DN150 before the reconstruction, a 325x12 mm sump with a shell length of 200 mm was welded and a nominal diameter of the DN50 with a product outlet nozzle D, which was welded in the center of the elliptical bottom of the sump. 3D models of capacity before and after reconstruction are shown in Figure 1 (a-b).



a)



b)

a) - 3D model of capacity before reconstruction;
b) - 3D model of capacity after reconstruction;

Fig. 1. 3D models of capacity before and after reconstruction.

Table 1 shows the values of permissible loads on nozzles K, A, C according to the operational and technical documentation.

Table 1. Values of allowable loads on nozzles according to operational and technical documentation.

Designation	Nominal passageway, DN, mm	Load values					
		Force, N			Moments, N·m		
		F_x	F_y	F_z	M_x	M_y	M_z
K	50	1400	1400	2000	360	360	500
A, C	500	12000	12000	16000	7200	7200	24000

The tasks were set to assess the values of the maximum acting stresses and identify the locations of their deployment in the tank housing, taking into account the operating operational parameters before and after its reconstruction, as well as taking into account the loads on the above nozzles with values of 50% and 75% of the permissible loads given in Table 1.

Also, for the central shell with a length of 600 mm, the vertical displacement of the edges of the upper edge up and down relative to adjacent shells was set by 2.4 mm, which is the maximum permissible value in the annular welds of vessels with a thickness of welded sheets of 14 mm in accordance with the current regulatory and technical documentation. At the above displacements, a strength analysis of the tank casing with operating operating parameters before and after the tank reconstruction was carried out, taking into account the loads on the above nozzles with values of 25%, 50% and 75% of the permissible loads given in Table 1. To study the trend of changes in the values of maximum stresses and zones of their concentration, the licensed software package "KOMPAS-3D" with the integrated APM FEM system was used to solve engineering and research problems.

3 Research results and discussion

The first step was to investigate the SSS of the vessel from the effects of pressure and temperature before and after reconstruction without taking into account the displacement of the central shell and loads on the nozzles. The results are shown in Figure 2-3. Values of stresses on the scale are given in MPa.

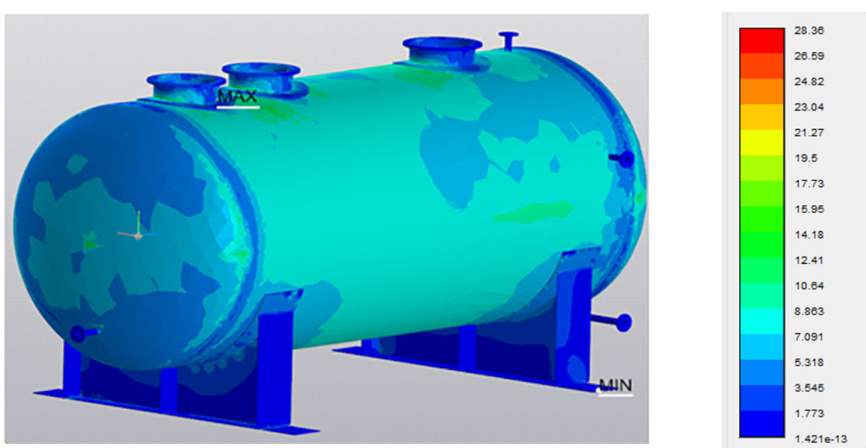


Fig. 2. Results of tank housing SSS study before reconstruction (internal overpressure is 0.1 MPa, temperature is plus 200 °C).

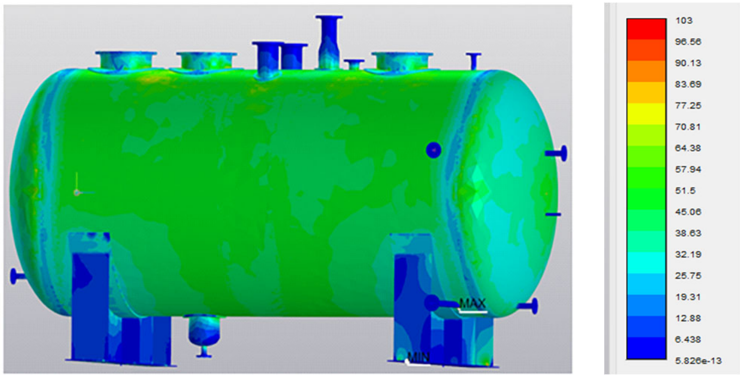
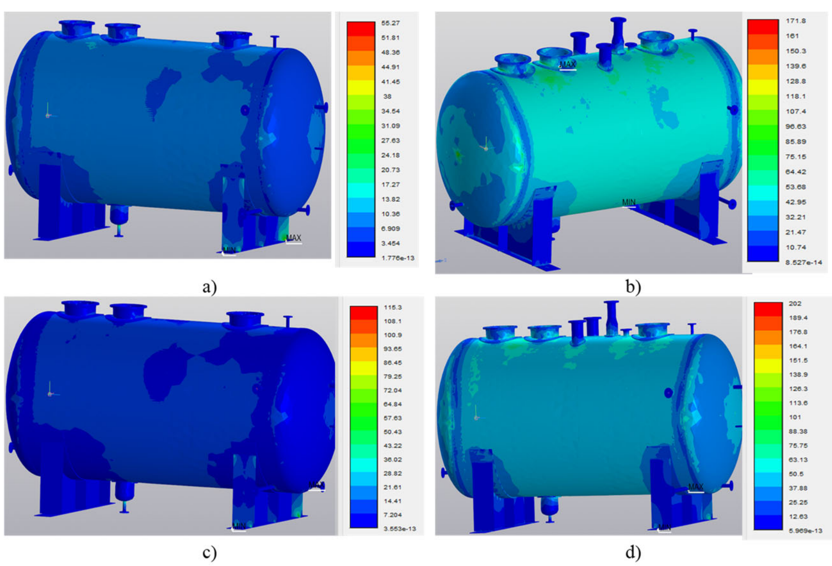


Fig. 3. Results of SSS study of the tank housing after reconstruction (internal overpressure is 0.6 MPa, temperature is plus 30 °C).

From the results obtained, it can be seen that in comparison before and after reconstruction, the tank body undergoes a fairly significant VAT change. So, for example, there was a change in the dislocation of the zone of action of maximum stresses, the area of action of increased stresses is concentrated almost throughout the surface of the case and the values increased by about 30 to 50 MPa in individual zones, the values of maximum stresses increased from 28.36 to 103 MPa.

Further, the SSS of the tank body was estimated for the above parameters before and after the reconstruction, taking into account the load on the nozzles KDN50, A, C DN500 with values of 50% and 75% of the permissible loads. Allowable loads on the considered nozzles are given in Table 1. The results are shown in Figures 4 a-d. Values of stresses on the scale are given in MPa.



a) - tank before reconstruction, loads on fittings are 50% of the permissible loads
b) – tank after reconstruction, loads on fittings are 50% of the permissible loads
c) – tank before reconstruction, loads on fittings are 75% of the permissible loads
d) - tank after reconstruction, loads on fittings are 75% of the permissible loads

Fig. 4. Results of the study of the stress-strain state of the tank body before and after reconstruction, taking into account pressure, temperature and loads on the fittings.

Analyzing Figures 4a-d, we can conclude that the application of loads on the nozzles makes a significant contribution to the formation of SPD of the tank body. The maximum stress values for the vessel housing increase before reconstruction from 28.36 MPa (excluding nozzle loads) to 55.27 MPa, taking into account loads with values of 50% of permissible loads and up to 115.3 MPa, taking inpeto account loads with values of 75% of permissible loads, respectively. The maximum stress values after reconstruction from 103MPa (excluding nozzle loads) were also recorded to 171.8MPa, taking into account nozzle loads with values of 50% of permissible loads and to 202MPa, taking into account nozzle loads with values of 75% of permissible loads, respectively. As before, there is a change in the concentration zones of maximum stresses. In certain cases, the maximum stresses are concentrated in the tie-in areas of the nozzles, and in others - in the areas of saddle supports. The shapes and size of the high stress concentration zones are also variable in each of the cases considered.

In conclusion of the research work, the SSS assessment of the tank body with parameters before and after the tank reconstruction was carried out while taking into account the loads on the above nozzles with values of 25, 50 and 75 from the permissible loads and taking into account the displacement of the edges of the upper edge of the central shell with a length of 600 mm. Displacement was set in vertical direction up and down relative to edges of adjacent shells by value 2.4 mm. For the comparative analysis, the SSS of the tank body was previously estimated, taking into account the displacement up and down by 2.4mm of the upper edge of the central shell 600 mm long, excluding loads on the nozzles. Values of maximum stresses in the body with parameters before and after reconstruction, considering the direction of displacement except for the central shells without taking into account the fittings, as well as the location of the maximum stresses, as indicated in Table 2. Values of maximum stresses in the body with parameters before and after reconstruction with Simultaneous taking into account the direction of displacement of the edges of the central shell and taking into account the supply to the fittings with values of 25%, 50% and 75% of the permissible displacements, as well as the location of the maximum stresses, as shown in Table 3.

Table 2. Values of maximum stresses in the tank body with parameters before and after reconstruction, taking into account the direction of displacement of the edges of the central shell without taking into account the loads on the fittings, as well as the location of the maximum stresses.

Scenario in question	**Maximum stress value, MPa**	**Location of maximum stress**
Tank before reconstruction, upward displacement of the edges of the upper part of the central shell	27.82	Nozzles C
Tank after reconstruction, upward displacement of the edges of the upper part of the central shell	93.00	Nozzles B
Tank before reconstruction, displacement of the edges of the upper part of the central shell downwards	27.66	Nozzles C
Tank after reconstruction, displacement of the edges of the upper part of the central shell downwards	101.00	Left bottom

Table 3. Values of maximum stresses in the tank body with parameters before and after reconstruction, simultaneously taking into account the direction of displacement of the edges of the central shell and taking into account loads on the fittings with values of 25%, 50% and 75% of the permissible loads, as well as the location of the maximum stresses.

Scenario in question	The magnitude of the loads on the fittings from the permissible loads, %	Maximum stress value, MPa	Location of maximum stress
Tank before reconstruction, upward displacement of the edges of the upper part of the central shell	25	39.40	Left bottom
Tank after reconstruction, upward displacement of the edges of the upper part of the central shell	25	171.90	Nozzles B
Tank before reconstruction, displacement of the edges of the upper part of the central shell downwards	25	29.97	Nozzles C
Tank after reconstruction, displacement of the edges of the upper part of the central shell downwards	25	170.50	Nozzles B
Tank before reconstruction, upward displacement of the edges of the upper part of the central shell	50	43.47	Right fixed support (rib)
Tank after reconstruction, upward displacement of the edges of the upper part of the central shell	50	196.00	Nozzles DN 50 next to the right fixed support
Tank before reconstruction, displacement of the edges of the upper part of the central shell downwards	50	43.51	Right fixed support (rib)
Tank after reconstruction, displacement of the edges of the upper part of the central shell downwards	50	171.90	Nozzles B
Емкость до реконструкции, смещение кромок верхней части центральной обечайки вверх	75	61.42	Right fixed support (rib)
Tank before reconstruction, upward displacement of the edges of the upper part of the central shell	75	219.00	Nozzles DN 50 next to the right fixed support
Tank before reconstruction, displacement of the edges of the upper part of the central shell downwards	75	81.55	Left bottom
Tank after reconstruction, displacement of the edges of the upper part of the central shell downwards	75	232.00	Left bottom

The results of the SSS study of the vessel housing before and after reconstruction taking into account the corresponding pressure, temperature, as well as the presence of displacement of the edges of the upper part of the central shell with a length of 600 mm relative to the edges of adjacent shells in the vertical direction by the value of 2.4 mm up and down without taking into account the load on the nozzles show the following. The tendency to change the values of maximum stresses is most pronounced for the case when reconstructing the tank taking into account the tie-in of new nozzles, as well as an increase in pressure. The direction of displacement in the vertical direction of the central shell with a length of 600 mm does not significantly affect the values of maximum stresses, which in both cases are of the order of 27 MPa. However, after the tank reconstruction, there is already a noticeable change in the values of maximum stresses compared to the option before the reconstruction and depending on the direction of displacement of the central shell. When the edges of the central shell are shifted up 2.4 mm, the maximum stresses are 93 MPa, and when the edges of the central shell are shifted down 101 MPa. The maximum stress concentration zones change. So, for example, when the edges of the central shell are displaced upwards, the maximum stress concentration zone is located in the tie-in zone of the BDN500 nozzle. When the direction of displacement of the edges of the central shell downward relative to adjacent shells changes, the place of concentration of maximum stresses changes and is observed in the center of the convex part of the left elliptical bottom.

With the subsequent application of loads on the nozzles in question of 25, 50 and 75 % of the allowable loads for the above scenarios, it can be seen that in all cases an increase in the value of loads on the nozzles leads to an increase in the values of maximum stresses. Increase of values of maximum stresses is of jump-like nature at value of applied loads on unions equal to 75% of permissible loads and greatest stress jumps are expressed in case when edges of central shell are displaced both up and down by 2.4 mm relative to edges of adjacent shells after reconstruction. So, for example, the maximum stresses increase by 43 MPa after reconstruction with an increase in the values of loads on the nozzles from 50 to 75 % of the permissible loads when the central shell is shifted upward, while the stress values increase by 17.95 MPa occurs in the event of an identical displacement and increase in loads on the nozzles until the tank is reconstructed. Maximum stresses increase by 60.1 MPa after reconstruction with increase of values of loads on nozzles from 50% to 75% of allowable loads in case of displacement of edges of central shell downwards, with increase of values of stresses by 38 MPa in case of identical displacement of edges and increase of loads on nozzles before reconstruction of tank. The size and shape of the areas of the zones of concentration of increased stresses is different. The location of the maximum stress concentration zones is non-constant and the characteristic zones for the above considered options are: the central part of the left elliptical bottom, the tie-in zone of the BDN500 connector, the fixed right support.

4 Conclusion

Based on the results of the tank SSS study, depending on the effect of the design change, by tapping new nozzles, changing operating parameters, taking into account the values of loads on the nozzles, as well as the possible presence of edge displacement in the annular weld in different vertical directions, the following conclusions were made:

- it was established that after tapping new process nozzles in addition to existing nozzles, as well as changing process parameters can have a cardinal effect on the value of maximum stresses and the formation of zones of increased stresses;
- it is shown that when loads on process nozzles increase, maximum stresses increase, and the pattern of stress increase is uneven, and the location and dimensions of zones of increased stresses change;

- it was established that a significant contribution to the growth and nature of the growth of maximum stress values taking into account changes in process parameters, the tie-in of new nozzles and loads on process nozzles can be caused by the direction of edge displacement in circular welded joints.

References

1. M.I. Bayazitov, V.K. Berdin, I.R. Kuzeev, R.R Tlyasheva, Oil and Gas Business **4**, 21-45 (2022). https://dx.doi.org/10.17122/ogbus-2022-4-21-45
2. K.N. Abdrakhmanova, R.R. Tlyasheva, D.N. Shermatov, R.O. Kadyrov, V.A. Gafarova, R.A. Gimaev, Oil and Gas Business **2**, 5-19 (2022). http://dx.doi.org/10.17122/ogbus-2022-2-5-19

   A.V. Rubtsov et al., J. Phys.: Conf. Ser. **1889** 042077 (2021). https://www.doi.org/10.1088/1742-6596/1889/4/042077.
3. V.A Gafarova., D.N. Shermatov, M.I. Bayazitov, A.L. Arslanov, Machines, units and processes in the oil and gas industry **21(5)** (2023). https://doi.org/10.17122/ngdelo-2023-5-198-211
4. M.M. Zakirnichnaya et al., J. Phys.: Conf. Ser. **2697** 012067 (2024). https://doi.org/10.1088/1742- 6596/2697/1/012067
5. K. Abdrakhmanova et al., AIP Conf. Proc. **2700** 020015 (2023). https://doi.org/10.1063/5.0125050
6. K. Abdrakhmanova et al., J. Phys.: Conf. Ser. **1889** 042089 (2021). https://doi.org/10.1088/1742- 6596/1889/4/042089
7. Z.R. Mazina et al., J. Phys.: Conf. Ser. **1515** 042041 (2020). https://doi.org/10.1088/1742-6596/1515/4/042041
8. Z.R. Mazina, R.R. Tlyasheva, IOP Conf. Ser.: Earth Environ. Sci. **459** 032037 (2020). https://doi.org/10.1088/1755-1315/459/3/032037
9. P.A. Kulakov et al., IOP Conf. Ser.: Mater. Sci. Eng. **753** 042087 (2020). https://doi.org/10.1088/1757- 899X/753/4/042087