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Development of design solutions for reduction of maximum stresses in the vessel housing

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Abstract. Process tanks of oil and gas industries, as a rule, have individual design and operational features, which to a decisive extent affect the zones of concentration of increased stresses and stress values in structural elements. Also, during operation, the structural elements of the tank to a greater or lesser extent can be subject to corrosion wear due to the structural materials of the working media. Thinning of the wall occurs, a decrease in the safety margin and, as a result, a redistribution of zones of concentration of increased stresses and an increase in the values of maximum stresses. In order to compensate for the high maximum stresses in the vessel body, it is advisable to install stiffening rings using welding. Each application of stiffening rings (dimensions, number, place of installation relative to other structural elements, installation on the inner or outer surface of the housing) is always individual in nature and should be determined depending on the operating conditions, the degree of damage and the design of the technical device.

1 Introduction

Modern science does not stand still and is developing dynamically in the field of developing new designs of technical devices of oil and gas enterprises, as well as new and relevant methods of manufacturing, installation, repair, operation, reconstruction, etc. using digital technologies. A significant amount of scientific work is devoted to the study of the behavior of technological equipment in various conditions using software systems that allow numerical modeling of technological equipment [1-2]. Works [3-4] show the nature of the change in the stress-strain state (SSS) of the equipment, taking into account the interaction of various factors and their possible impact on SSS. Currently, an urgent issue is to reduce the values of maximum stresses in structures due to the development of various non-standard design solutions [5-6]. One such solution can be the use of stiffening rings, since stiffening rings are usually used in oil and gas equipment to reduce the metal consumption of cylindrical housings by reducing the required wall thickness. The study of possible applications of stiffening rings using specialized programs that allow strength analysis can help to find new approaches to solving problems to reduce stress values [7].

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2 Research methodology

The object of the study is the process capacity. A detailed description of the tank, its purpose, design and operational features are described in [8]. The three-dimensional model of the capacity is built in the KOMRAS-3D PC, and in the integrated APM FEM system it is divided into finite elements. The 3D model of the tank is shown in Figure 1.

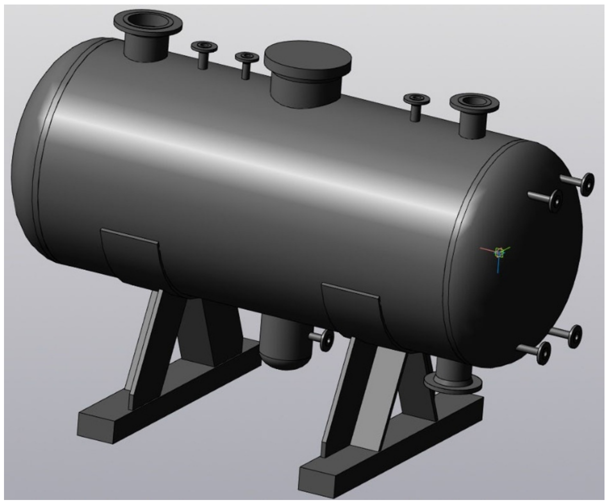


Fig. 1. 3D-capacity model.

Earlier in work [8], the SSS of the process tank body was evaluated taking into account the operating loads and excluding the loads from pipelines connected to the product inlet and outlet nozzles. It was found that the distribution of SSS in the body of the process tank with the sequential addition of nozzles is uneven. In some cases, there is an increase in the values of maximum stresses. However, in certain cases, the voltage values decrease or their abrupt increase occurs, which may be associated with the redistribution of capacity SSS due to the mutual influence of the nozzles. It is also characteristic to change the location of stress concentration zones and their dimensions. The SSS of the process vessel body was also evaluated taking into account the operating loads, taking into account the decrease in wall thickness to 18 mm, 16 mm and 14 mm, as well as taking into account the loads from pipelines connected to the product inlet and outlet nozzles. It is shown that with an increase in the applied operational loads from the piping (up to 45% of the permissible values), the maximum stresses increase approximately 1.1-1.2 times. As the wall thickness decreases, there is a visible increase in maximum stresses. So, for example, when reducing the wall thickness of the container body from 20 mm to 18 mm, the maximum stress values increase from 195.9 MPa to 268.4 MPa. With an increase in load values up to 45% of the permissible, the values of maximum stresses increase significantly - by 1.5 times.

In order to reduce the maximum stresses in the body of the process vessel, a structural solution to the problem is proposed based on the use of stiffening rings with different sizes and locations.

The stiffening ring was located on the inside of the cylindrical shell of the process vessel. Stiffening ring profile is angle. The stiffening ring material is low alloy 09G2S steel. At the first stage of the strength analysis of the process tank, one stiffening ring was taken into account, the profile of which is an angle with dimensions of 20 × 20 × 3 mm (Figure 2).

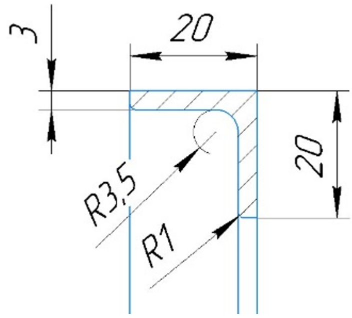


Fig. 2. Sketch of angle profile with dimensions 20 × 20 × 3 mm.

Initially, the stiffening ring was located at a distance of 2370 mm from the left edge of the edge of the cylindrical shell. A schematic representation of the location of the stiffening ring on the inner side of the cylindrical shell of the tank is shown in Figure 3.

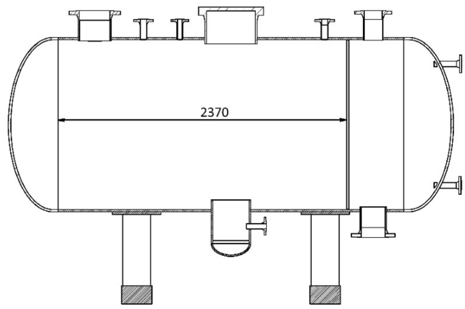


Fig. 3. Schematic representation of the location of the stiffening ring, representing a corner with dimensions 20 × 20 × 3 mm, on the inside cylindrical shell of the tank.

In continuation of the studies, the dimensions of the angle profile were taken equal to 25 × 25 × 4 mm, the stiffening ring was located at a distance of 1120 mm from the left edge of the edge of the cylindrical shell.

A schematic diagram of the location of the stiffening ring on the inner side of the cylindrical shell of the tank is shown in Figure 4.

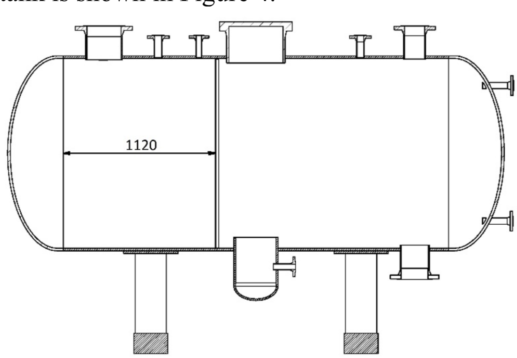


Fig. 4. Schematic representation of the location of the stiffening ring, representing a corner with dimensions 25 × 25 × 4 mm, on the insidecylindrical shell of the tank.

After considering the above options, the case was considered taking into account two stiffening rings, the dimensions of the profile of each of which are 40 × 40 × 5 mm. One stiffening ring was welded at a distance of 1160 mm from the left edge of the tank shell, the other - at 1640 mm. A schematic diagram of the location of two stiffening rings on the inner side of the cylindrical shell of the tank is shown in Figure 5.

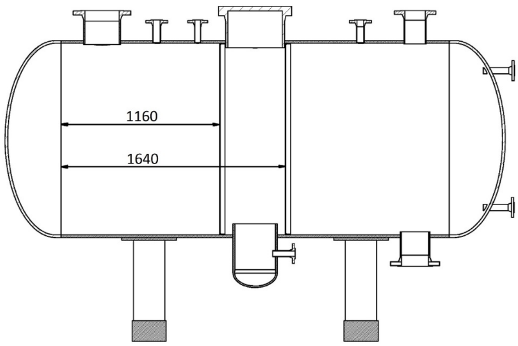


Fig. 5. Schematic diagram of the location of two stiffening rings, which are corners, with dimensions of 40 × 40 × 5 mm on the inner side of the cylindrical shell of the tank.

The location of the stiffening rings in the 3D model of the process tank is shown in Figure 6.

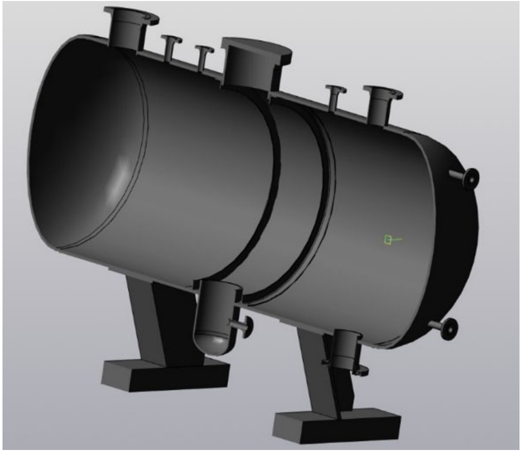


Fig. 6. Arrangement of stiffening rings in the 3D model of the process tank.

To calculate the SSS of the process capacity, a grid with a maximum element side equal to 122 mm was selected and the KOMPAS-3D licensed software package with the integrated APM FEM system was used. The stress values on the scales are given in MPa.

3 Research results and discussion

For comparative analysis, Figure 7 shows the SSS distribution of the process capacity due to operating pressure and temperature, excluding stiffening rings.

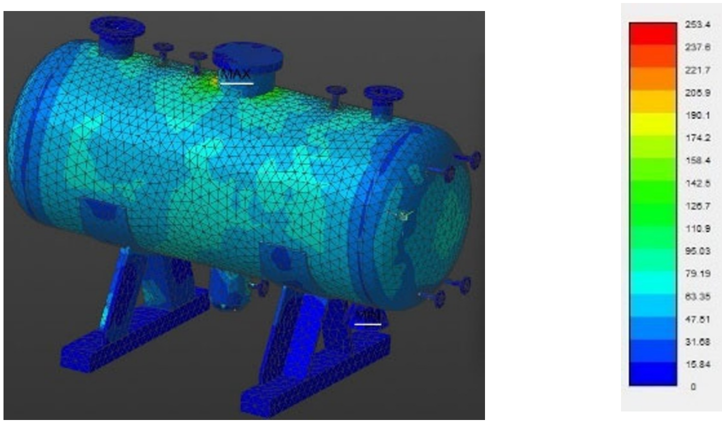


Fig. 7. Process capacity SSS allocation from the action of working pressure and temperature without taking into account stiffening rings.

Areas of increased stress concentration with values of 79.19 MPa are non-uniform and are mainly distributed in the areas of nozzle tie-ins, bottom and cylindrical shell joints, as well as in the welding areas of supporting structures and in the supports themselves.

For comparison, Figure 8 shows the distribution of SSS of the process capacity from the action of working pressure and temperature, taking into account the stiffening ring with dimensions of 20 × 20 × 3 mm on the inner side of the cylindrical shell at a distance of 2370 mm from the left edge of the shell.

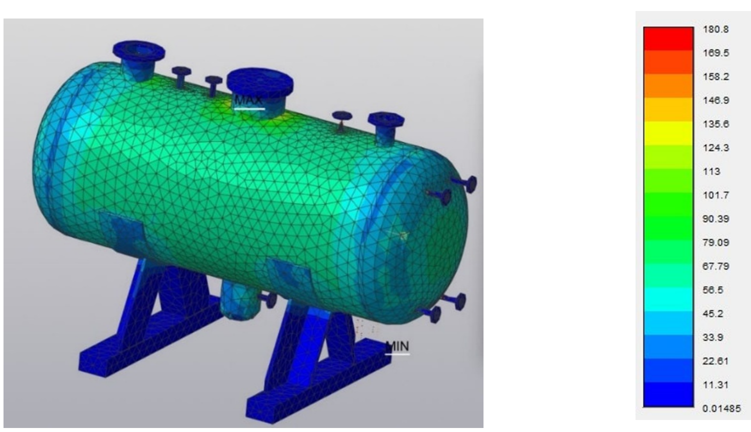


Fig. 8. Process capacity SSS allocation from the effect of working pressure and temperature, taking into account the stiffening ring dimensions 20 × 20 × 3 mm on the inner side of the cylindrical shell at a distance of 2370 mm from the left edge of the shell.

It can be seen that the maximum stresses are also concentrated in the hatch tie-in area, but 1.4 times less compared to the option without the use of a stiffening ring and amount to 180.8 MPa. There is also a more uniform distribution of the prevailing stresses of 79.1 MPa in the cylindrical shell.

Figure 9 shows the SSS distribution of the process tank from the action of working pressure and temperature, taking into account the stiffening ring with dimensions of 25 × 25 × 4 mm on the inner side of the cylindrical shell at a distance of 1120 mm from the left edge of the shell.

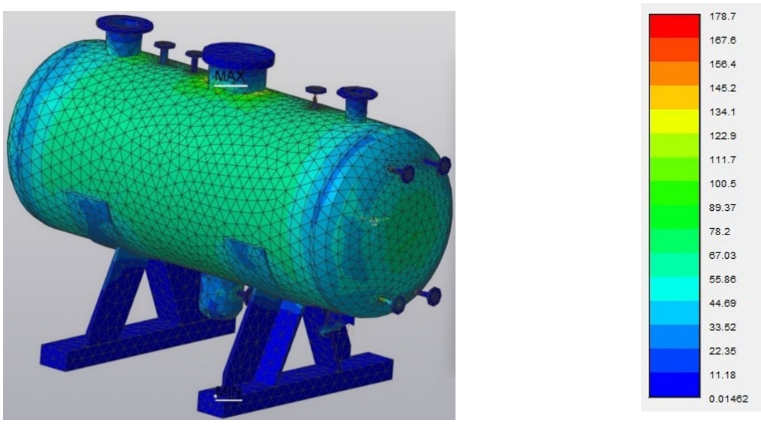


Fig. 9. Process capacity SSS allocation from the effect of working pressure and temperature, taking into account the stiffening ring dimensions 25 × 25 × 4 mm on the inner side of the cylindrical shell at a distance of 1120 mm from the left edge of the shell.

Comparing the results obtained in Figures 8 and 9, it can be seen that the maximum voltages decreased by another 2.1 MPa from 180.8 MPa to 178.7 MPa. The distribution of high voltage zones in the case remained unchanged, however, the values of prevailing voltages decreased from 79.1 MPa to 78.2 MPa.

The distribution of SSS of the process vessel due to the impact of working pressure and temperature, taking into account two stiffening rings with dimensions of 40 × 40 × 5 mm on the inner side of the cylindrical shell at a distance of 1160 mm and 1640 mm from the left edge of the shell, respectively, is shown in Figure 10.

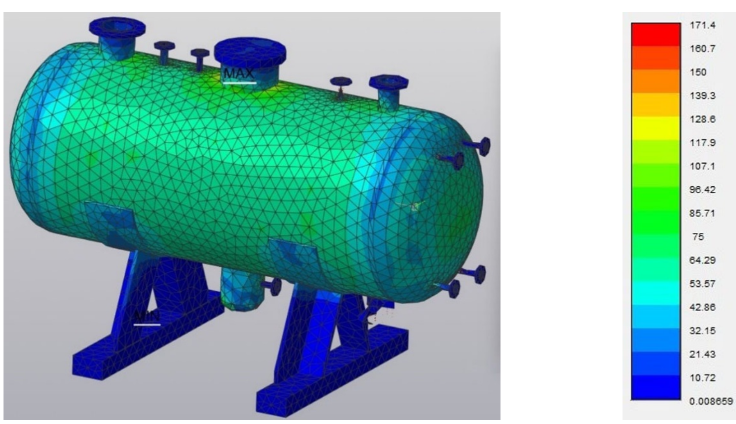
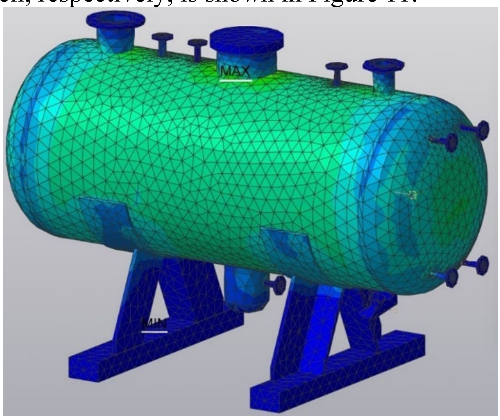


Fig. 10. Distribution of SSS of the process tank from the action of working pressure and temperature, taking into account two stiffening rings with dimensions of 40 × 40 × 5 mm on the inner side of the cylindrical shell at a distance of 1160 mm and 1640 mm from the left edge of the shell, respectively.

In this case, the maximum stresses are 171.4 MPa, which is 82 MPa less than the case without stiffening rings. The casing stresses are 64.3 MPa compared to 79.2 MPa without stiffening rings.

Further, the calculation was carried out by increasing the size of the stiffening rings from 40 × 40 × 5 mm to 60 × 60 × 6 mm. The location of the stiffening rings remains unchanged from the previous version.

Distribution of SSS of the process vessel from the action of working pressure and temperature, taking into account two stiffening rings with dimensions of 60 × 60 × 6 mm on the inner side of the cylindrical shell at a distance of 1160 mm and 1640 mm from the left edge of the shell, respectively, is shown in Figure 11.



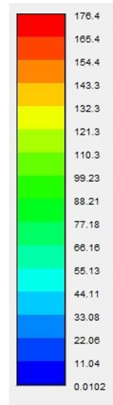


Fig. 11. Process capacity SSS distribution from impact operating pressure and temperature, taking into account two stiffening rings with dimensions 60 × 60 × 6 mm on the inner side of the cylindrical shell at a distance of 1160 mm and 1640 mm from the left edge of the shell, respectively.

As can be seen from the results obtained, an increase in the size of the stiffening rings led to an increase in the maximum stresses from 171.4 MPa to 176.4 MPa. This may be because the structure is given greater undesirable stiffness by increasing the size of the stiffening rings.

4 Conclusion

Analyzing the results obtained in this work, we can draw the following conclusions that it is advisable to use stiffening rings to reduce the values of maximum stresses in the body of the technological tank. So, for example, the maximum stresses in the area of the hatch tie-in DN400 mm are 1.4 times higher without the use of a stiffening ring compared to the option of using a stiffening ring with dimensions of 20 × 20 × 3 mm at a distance of 2370 mm from the left edge of the shell. In the course of research, it was found that the dimensions of the stiffening rings, their number and location have a significant impact on the distribution of SSS in the body of the process tank, as well as the values of maximum stresses. So, when increasing the dimensions of the stiffening ring to 25 × 25 × 4 mm and changing the location of the ring relative to the left edge of the shell from 2370 mm to 1120 mm, a slight, but still a decrease in the maximum stresses by 2.1 MPa is observed. When using two stiffening rings with dimensions of 40 × 40 × 5 mm at a distance of 1160 mm and 1640 mm from the left edge of the shell, respectively, a significant decrease in the maximum stresses is observed. The maximum stress values decreased by almost 1.5 times when using two stiffening rings compared to the case when no stiffening rings were used. When using two stiffening rings measuring 60 × 60 × 6mm, the opposite pattern is observed. There is an increase in maximum stresses by 5 MPa compared to the similar use of stiffening rings of a smaller dimension of their location. Also, when using stiffening rings of different sizes and locations, there is a change in the values of the prevailing stresses distributed in the container body. Based on the studies, it can be seen that the use of stiffening rings of different sizes and locations on the casings of capacitive equipment does not always give the required positive result in reducing stress values. Therefore, taking into account the individual design and operational features of capacitive equipment, it is necessary to select the size, number and location of the stiffening rings experimentally in order to obtain the most favorable option in terms of stress values and the nature of their distribution.

References

1. K. Khalfaoui, M. Zorn, C. Ségoufin, F. André, J. Kerner, S. Riedelbauch, Eng. Fail. Anal. **162**, 108428 (2024).
2. K. Rasiulis, A. Šapalas, R. Vadlūga, M. Samofalov, J. Constr. Steel R. **62**, 1232-1237 (2006).
3. B. Zhu, N. Leung, B. Steel, D. England, Y. He, A. London, H. Zhang, M. Gorley, Y. Wang, M. Whiting, T. Sui, Mater. Des. **248**, 113449 (2024).
4. K. Wang, X. Zhou, J. Zhou, J. Tan, Y. Wang, J. Xin, Eng. Struct. **332**, 120070 (2025).
5. H. Ahmadi, E. Zavvar, Thin-Walled Struct. **91**, 82-91 (2015).
6. S. Devi, K. Singh, Structures **26**, 66-78 (2020).
7. G. Krishna, S. Nallayarasu, Appl. Ocean Res. **126**, 103288 (2022).
8. M. Zakirnichnaya, A. Rubtsov, A. Gabbasova, M. Bayazitov, R. Tlyasheva, Bull. TulSU Tech. Sci. **1**, 582-590 (2024).