Stress-strain state assessment capacitive apparatus taking into account impact piping for connectors

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Abstract. Capacitive equipment in oil refining and petrochemical processes belongs to one of the most significant and responsible groups of process equipment of hazardous production facilities. Having various purposes, an impressive part of the process vessels is operated at increased pressures and temperatures under conditions of corrosion-erosion wear. Therefore, capacitive equipment must meet all the necessary requirements in the field of reliability and industrial safety. Depending on the effect of various operational loads and other factors, the distribution of the stress-strain state of the equipment elements can vary according to various scenarios depending on the determining parameter of the technical state and the dominant damage mechanism. One such factor may be the loads on the nozzles from process pipelines. The geometry features and various operational parameters of the piping can have a significant effect on the formation of the stress-strain state of the vessel and the distribution of areas of concentration of increased stresses. In the future, defects of various levels may occur in these zones. In this regard, the work on the study of the stress-strain state of the vessel is relevant, taking into account the loads that pipelines from the process piping exert on the nozzles.

1. Introduction
At oil refining and petrochemicals, a significant part, both in terms of metal consumption and in terms of use in technological processes, is occupied by capacitive-type equipment. Process tanks have various purposes and are operated at high pressures and temperatures, as well as in conditions of explosion and fire hazardous and aggressive media. In the conditions of operation under the above mentioned factors, one of the first places is the development of solutions for ensuring the reliability and industrial safety of facilities. Moreover, the necessary reliability and reliability conditions should be fulfilled throughout the life cycle of the equipment starting from design and ending with the transition of the object to the limit state. As the analysis of literary sources shows, one of the main reasons for premature failure of capacitive devices is corrosion wear, process disruption, as well as failure of control and protection equipment. The existing regulatory and technical documents for the design and technical diagnosis of vessels and devices reflect all the necessary norms and regulations to ensure reliable and safe operation in terms of strength and level of defects. However, all existing methods do not take into account scenarios for changing the stress-strain state (VAT) of equipment elements from the influence of various external and internal factors. The distribution of the zones of concentration of increased stresses is often uneven and may imply the formation of potential zones of onset of defects. In this regard, a study on the assessment of the degree of inhomogeneity of VAT distribution in the process vessel housing, taking into account the loads on the nozzles created by pipeline piping, is relevant.
2. Methodology of the research

A buffer tank of one of the petrochemical plants with the following structural and operational parameters was chosen for the studies: the diameter of the hull is 2400 mm; body length - 10000 mm; body wall thickness - 22 mm; design temperature - plus 50 °C; design pressure - 0.65 MPa; material - steel 20.

The characteristics of the buffer tank process piping are shown in table 1.

| Appointment       | Diameter, mm | Category | Group |
|-------------------|--------------|----------|-------|
| gas inlet         | 50           | B(a)     | II    |
| gas output        | 50           | B(b)     | II    |
| liquid outlet     | 100          | B(a)     | II    |
| gas inlet         | 150          |          |       |
| gas inlet         | 350          |          |       |

At the first stage, a 3D model of buffer capacity was built using the KOMRAS-3D PC. The 3D model of the buffer tank with the letter designations of the process nozzles is shown in figure 1.

![Figure 1. 3D model of buffer tank with letter designations of process nozzles.](image1)

At the second stage, a 3D model of the buffer tank with piping was built according to the process diagram of the vessel switching on using PC "KOMRAS-3D" (figure 2).

Further, in order to estimate the VAT, the piping tanks were selected and designed for the strength of the most important gas inlet and outlet pipelines with a diameter of 350 mm (according to table 1 and figure 2). Construction and calculation of pipelines was carried out in PC "START," which is designed to calculate the strength and rigidity of pipelines for various purposes. When you draw each pipe part (run), you set the necessary parameters. 3D pipe models are shown in figure 3.

When performing calculations of pipelines in PC "START" it is established that distribution force, not bending moment, has the most significant influence from loads acting on piping. Therefore, a distribution load F with the following values was applied to the nozzles of the buffer tank, technologically connected to the gas inlet and outlet pipelines with diameters of 350 mm in further calculations:

- 9571 N for LH connector B with diameter of 350 mm (process connected to the pipe shown in figure 3b);
4644 N for RH connector J with the diameter of 350 mm (process connected to the pipe shown in figure 3a).

The finite element method was used to solve the capacity assessment (VAT) problem. This method, due to its versatility, is especially effective, since it allows solving complex problems in three-dimensional staging with any detail of the object of study and any types of applied loads, as well as allows using real models of material behavior in which material properties depend on temperature, strain rate, etc.

The VAT evaluation of the vessel was carried out for the case wall thickness thinning scenario at a temperature of 50 °C, pressure of 0.65 MPa, without corrosion wear and with corrosion wear of 5 mm, 8 mm, 11 mm and 12 mm.

3. Research results and discussion
At the first stage, the VAT of the buffer tank was evaluated without taking into account the loads on the nozzles and taking into account corrosion wear. The VAT distribution of the tank without taking into account the loads on the nozzles is shown in figure 4.
According to the results of the VAT assessment shown in Figure 4, it was established that the maximum voltages are 97.82 MPa and are concentrated on the vessel housing in the hatch welding area.

At the second stage, the VAT of the buffer tank was evaluated taking into account the loads on the connectors from the piping without taking into account corrosion wear (distribution loads equal to 9571 N for the left connector B and 4644 N for the right connector J). The VAT distribution of the tank with loads on the nozzles from the piping is shown in Figure 5.

By analyzing the result, we can conclude that the maximum stresses, taking into account the loads on the nozzles from the piping, are about 53 MPa higher than the scenario without taking into account the loads. Therefore, further VAT calculations were carried out taking into account the loads on the nozzles from the pipelines. The next stage of the study was the identification of dependence and corrosion wear on VAT of the buffer vessel housing. Figures 6-10 show the results of the VAT.
distribution of the vessel housing at a pressure of 0.65 MPa and a temperature of 50 °C with corrosion wear of 5 mm, 8 mm, 11 mm and 12 mm.

Figure 6. VAT distribution of buffer tank with corrosion wear of 5 mm (shell thickness is $S = 17$ mm).

Figure 7. VAT distribution of buffer tank with corrosion wear of 8 mm (shell thickness is $S = 14$ mm).

Figure 8. VAT distribution of buffer tank with corrosion wear of 11 mm (shell thickness is $S = 11$ mm).
Figure 9. VAT distribution of buffer tank with corrosion wear 12 mm (shell thickness is S = 10 mm).

By analyzing the results given in figures 6-9, it can be concluded that when the wall thickness of the buffer vessel housing is thinned, the maximum stresses increase. Moreover, with the thickness of the tank body wall S = 10 mm, the values of maximum stresses 147.7 MPa by 2.7 MPa exceed the permissible stresses for the shell material at the design temperature (for steel 20 at the design temperature t = 50 °C [σ] = 145 MPa).

Next, for comparative analysis, the rejection wall thickness was calculated in accordance with the regulatory documents according to the formula:

$$s_p = \frac{p \cdot D}{2 \cdot [\sigma] \cdot \varphi - p},$$

(1)

Where p is the design pressure, MPa;
D - internal diameter, mm;
[σ] - permissible stresses, MPa;
φ - coefficient of durability of a weld joint, was accepted by 0.9.

The results of calculation of rejection thicknesses of the buffer vessel housing wall and values of maximum stresses at different values of corrosion wear of the housing are given in table 2.

Table 2. Results of calculation of rejection thicknesses of the buffer vessel housing wall and values of maximum stresses at different values of corrosion wear of the housing.

| Temperature t, °C | Pressure p, MPa | Wall thickness s, mm | Thinning δ, mm | Reject thickness s_otb, mm | Maximum stress σ_max, MPa | Allowable stress for material at design temperature [σ], MPa |
|------------------|----------------|----------------------|---------------|--------------------------|--------------------------|-----------------------------|
| 50               | 0.65           | 22                   | 0             | 5.39                     | 46.86                    | 145                         |
|                  |                | 17                   | 5             |                          | 84.35                    |                             |
|                  |                | 14                   | 8             | 11                       | 95.57                    |                             |
|                  |                | 10                   | 11            | 12                       | 135.8                    |                             |
|                  |                |                      |               |                          | 147.7                    |                             |

4. Conclusion

Based on the results of the assessment of the degree of non-uniformity of VAT distribution in the process vessel housing, taking into account the loads on the nozzles created by pipeline piping, the following conclusions can be drawn:
• it is shown that taking into account the loads on the connectors from the process pipelines, it is possible to detect additional zones of stress concentration outside the places where the connectors are welded.
• it has been established that the values of maximum stresses in the process vessel housing can be higher than the permissible stresses at wall thicknesses higher than the rejection values obtained at the design stage.

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