Modeling of the stressed-deformed state of the apparatus under pressure at corrosion

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Abstract. Vessels and apparatuses operating under pressure at hazardous production facilities are operated under conditions of many factors that limit the safe service life. These factors include elevated pressures and temperatures, damage during operation, exposure to both static and cyclic loads, etc. The most common and determining damage to metal equipment is corrosion wear. Corrosion wear negatively affects reliability during operation, gradually reducing the strength of the technical device by reducing wall thicknesses and thereby bringing the object closer to its ultimate state. As a rule, visual inspection and thickness measurements make it possible to identify corrosion zones, analyze these zones and give recommendations for further operation or replacement of defective areas. However, some designs of vessels and apparatuses do not give the opportunity to carry out work on the assessment of the corrosion state in full, and in this regard, there is a possibility that adverse sections will be skipped. Especially such problems arise when diagnosing devices with multiple workspaces. Currently, the work on modeling equipment of this type with the use of specialized software systems for assessing the stress-deformed state taking into account all the factors present and identifying the most unfavorable zones with maximum effective stresses is relevant. In this paper, we study the interconnection between the effect on the apparatus with a shirt of operating parameters when modeling various scenarios of corrosion wear.

1. Introduction

The technological processes of oil and gas refining and petrochemical complexes cannot be implemented without exposure to hydrocarbon feeds of excessive pressures and elevated temperatures using appropriate vessels or apparatuses. It is in the vessels and apparatuses that the necessary processes occur, established by the technological regulations. For their implementation, technical devices of various types and designs are used. Some devices are designed for mass transfer processes, others for heat transfer processes, others for chemical reactions, etc. Very often, the above equipment is operated under the influence of corrosive media to a greater or lesser extent. Corrosion processes occurring during the operation of the equipment are the main reason for the decrease in the safety margin of its structural elements and, as a result, the increase in the values of the operating stresses. The reduction of safety margin occurs due to thinning of the walls, sometimes to unacceptable thicknesses, regulated by regulatory documents. To assess the corrosive state of the surface of the structural elements of vessels and apparatuses operating under pressure, the current methods have
mainly established two non-destructive testing methods: visual and measuring control using specialized tools, as well as ultrasonic thickness gauging. Visual and measuring control allows you to identify the type of corrosion, the zone of corrosion wear and determine the area of damage. Ultrasonic thickness measurement allows you to quantify the degree of wear and compare the minimum measured thicknesses with acceptable thicknesses.

Existing normative techniques regulate the following minimum requirements for visual and measuring control, as well as ultrasonic thickness measurement:

- 100% visual and measuring control in accessible places inside and outside the device;
- thickness measurement can be performed both on the outer and inner surfaces of the vessel. Measurements are carried out on four forming of the shell and four radii of the bottoms through 90° around the circumference of the element. At each shell of the vessel, limited by welds, at least three thickness measurements are made for each forming (in the middle and at the edges). At least five thickness measurements are carried out on the bottoms, and at least four on the nozzle nozzles. This is the minimum control volume for vessels and apparatus subjected to uniform corrosion.

In the case of increased aggressiveness of the working environment and the presence of zones and areas in which more intense wear is possible, the number of thickness measurements may increase. The places of measurements and the required number of points are determined by the expert conducting the diagnosis based on the results of the visual inspection.

However, in some apparatuses with an individual unique design, 100% visual and measuring control is difficult to carry out to the necessary extent, and in some cases even impossible. Consequently, unfavorable areas may remain uncontrolled, which subsequently can lead to the development of depressurization, and as a result of an emergency scenario.

Also, in normative and technical documents, during analysis and calculations, the actual stress-deformed state (SDS) arising in a vessel or apparatus is not taken into account, taking into account the presence of corrosion wear.

Therefore, an urgent task is to simulate the SDS of apparatus operating under pressure and having two working spaces, under different scenarios of corrosion wear in order to identify zones of maximum effective stresses [1-5].

2. The research method

To conduct a study of the interconnection between the impact of operational loads, corrosion, and design on the SDS of an apparatus with a shirt, an identical apparatus of one of the manufacturers was chosen. The shell material of the main apparatus is cast iron of the SCH 15-32 type, the bottom and the detachable bonnet of the main apparatus is cast iron of the SCH 18-36 type. The material of the shell and elliptical bottom of the shirt is carbon steel of ordinary quality St3.

The apparatus with a shirt is a vertical apparatus consisting of a solid cast-iron body of the main apparatus, including a cylindrical shell and a bottom, a removable bonnet of the body, a steel cylindrical shell of a shirt, a welded steel elliptical bottom of a shirt, technological fittings and is mounted on support legs at a height. The apparatus is intended for heating a petrochemical product to the required process temperature. In the research process, the KOMPAS-3D licensed software package was used with the APM FEM system integrated in it for solving engineering and research problems.

This system is built into the software product and allows modeling to solve strength and thermal problems. The procedure is performed in three stages:

- adoption of a method of fixing and application of existing loads and temperatures;
- creating a finite element mesh, its optimization according to various criteria;
- execution of the calculation.

At the first stage, a model of the apparatus with a shirt was built in the KOMPAS-3D program. Then, using the APM FEM strength analysis system, which is included in the KOMPAS-3D software package, loads such as pressure and temperature were applied; fixed fixtures. After that, a finite elementary mesh was created using the CE-mesh generation command, and VAT calculation was
performed. As a result of the calculations performed by the APM FEM system, a map of the
distribution of loads, stresses and deformations in the structure was obtained [6-8].
The constructed model of the apparatus with a shirt is shown in Figure 1.

![Figure 1](image)

**Figure 1.** Built model of the apparatus with a shirt.

3. **The results of the research and discussion**

The overall task of the study was to assess the SDS of the apparatus under several possible scenarios
of corrosion wear of the case, both the apparatus itself and the shirt body under operating conditions.

Individual tasks were as follows [9-14]:

1) an assessment of the SDS of the apparatus when the inner surface of the apparatus is worn above the shirt by 0.1 mm, and the wear of the inner surface of the apparatus under the shirt and the inner surface of the shirt by 0.2 mm;

2) the SDS assessment of the apparatus when the inner surface of the apparatus is worn above the shirt by 0.1 mm, and the wear of the inner surface of the apparatus under the shirt and the inner surface of the shirt by 0.4 mm;

3) assessment of the SDS of the apparatus when the internal surface of the apparatus’s body is worn over the shirt, as well as the wear of the internal surface of the apparatus’s body under the shirt and the internal surface of the shirt by 0.2 mm;

4) the SDS assessment of the apparatus when the inner surface of the apparatus is worn over the shirt by 0.2 mm, and the wear of the inner surface of the apparatus under the shirt and the inner surface of the shirt by 0.3 mm;

5) an assessment of the SDS of the apparatus when the inner surface of the apparatus above the shirt is 0.1 mm worn, the inner and outer surfaces of the apparatus under the shirt is 0.2 mm each and the inner surface of the shirt is 0.2 mm less;

6) the SDS assessment of the apparatus when the inner surface of the apparatus above the shirt is 0.1 mm worn, the inner and outer surfaces of the apparatus under the shirt is 0.3 mm each and the inner surface of the shirt is 0.3 mm less wear;

7) the SDS assessment of the apparatus when the inner surface of the apparatus above the shirt is 0.1 mm wear, the inner and outer surfaces of the apparatus under the shirt is 0.4 mm each and the inner surface of the shirt is 0.4 mm more wear.

The research results of tasks 1-7 are shown in Figures 2-3.

As can be seen from the above figures, the maximum stresses of the apparatus with the shirt arise in the place of welding of the support legs in the body of the steel shirt. The values of the maximum stresses are fixed at a minimum difference in corrosion wear to 0.1 mm of the inner surface of the apparatus body above the shirt towards to the wear of the inner and outer surfaces of the apparatus...
body under the shirt separately and the wear of the inner surface of the shirt body. With an increase in the difference of corrosion wear of the above surfaces by 0.2 and 0.3 mm, a decrease in the maximum effective stresses is observed in 1.5–1.6 and almost 3.5 times, respectively.

Figure 2. The results of assessing the SDS of the apparatus when setting objectives 1 ÷ 3.

Figure 3. The results of the assessment of the SDS apparatus when setting tasks 4 ÷ 7.
Moreover, with an increase in the difference of corrosion wear by 0.3 mm towards to the wear of the inner surface of the apparatus body above the shirt to the wear of the inner and outer surfaces of the apparatus under the shirt separately, as well as the wear of the inner surface of the shirt body, significant deformation of the bottom and distribution of increased stresses are observed over the entire body of the shirt apparatus.

To prevent deformation during thinning of the wall thickness of the main elements of the apparatus with a jacket, the use of a stiffening ring was proposed. The first was a variant of welding the stiffening ring to the shirt body from the inside at a distance of 100 mm from the top edge of the shirt in order to give additional rigidity. The stiffness ring is a 15 × 15 × 4 mm corner made of Cr3 steel. The second option was simulated version of welding the stiffening ring to the body of the shirt outside at a distance of 50 mm from the top edge of the shirt. The third option was simulated version of welding the stiffening ring to the body of the shirt on the outside at a distance of 20 mm from the bottom edge of the shirt. The places of welding of the stiffening ring were chosen for reasons of structural availability of the welding process. Modeling was carried out under the most unfavorable scenario of corrosion wear specified in task 7. The results of calculating the SDS of the apparatus with a stiffening ring on the inside and outside of the shirt are shown in Figure 4.

Figure 4. Results of calculating the SDS of the apparatus with a stiffening ring on the inside and outside of the shirt.
Analyzing Figure 4, it can be seen that the minimum stresses of 44.2 MPa, in the absence of deformation of the bottom of the shirt, are observed provided that the stiffening ring is welded to the shirt body from the inside at a distance of 100 mm from the top edge of the shirt.

4. Conclusion

Based on the results of modeling the SDS of an apparatus with a shirt under various corrosion wear scenarios, the following conclusions can be made:

- it was found that the maximum stresses are typical for cases when the difference in the corrosion wear of the inner surface of the apparatus body above the shirt towards to the wear of the inner and outer surfaces of the apparatus body under the shirt and the wear of the inner surface of the shirt body is up to 0.1 mm;
- it is shown that the values of the maximum occurring stresses decrease by 1.5–1.6 and almost 3.5 times with an increase in the difference of corrosion wear by 0.2 and 0.3 mm, respectively, of the inner surface of the apparatus body above the shirt towards to the inner wear and the outer surfaces of the body of the apparatus under the shirt and the wear of the inner surface of the shirt body. Moreover, with an increase in the difference of corrosion wear by 0.3 mm towards to the wear of the inner surface of the apparatus body above the shirt to the wear of the inner and outer surfaces of the apparatus under the shirt separately, as well as the wear of the inner surface of the shirt body, a significant deformation of the bottom and the distribution of increased stresses are observed throughout the body of the shirt apparatus;
- it was found that in order to protect the apparatus with the shirt from deformation and reduce the maximum possible stresses, it is advisable to use stiffening rings, the structural dimensions of which and location should be determined by modeling the SDS of the apparatus in question. Moreover, a more preferred option is the location of the stiffening ring on the inner surface of the cylindrical body of the shirt.

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