Modeling a stressed-deformed state of a technological apparatus

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Abstract. The operation of devices with a shirt is carried out at high pressures and temperatures in corrosive environments. This is a prerequisite for the development of such a damage mechanism as a decrease in wall thickness and loss of strength. For a quantitative assessment of the degree of corrosion wear and prediction of the further period of safe operation of the apparatus, standard methods and techniques are used, which are indicated in the current regulatory and technical documentation for diagnosing and evaluating the resource. For apparatuses with a shirt, access to a complete 100% inspection of the inner surface of both the main apparatus and the shirt is difficult due to the design features and the absence of a hatch of sufficient diameter. In this regard, a large error in the qualitative assessment of the technical condition and resource forecasting is possible. Currently relevant is the work on modeling apparatuses and assessing the stress-deformed state, taking into account their design and operational features, taking into account changes in the parameters of the technical condition, such as corrosion wear, and identifying the most loaded zones and areas with a view to their further detailed diagnosis. In this paper, we study the interconnection between the effects of operational loads and corrosion wear, both of the apparatus itself and the shirt on the stress-deformed state of the apparatus as a whole.

1. Introduction

At the enterprises of oil and gas refining and petrochemicals, various economically important technological processes take place with the participation of a huge number of different types of vessels and apparatuses. Most of this equipment has been in operation for quite some time and, as a rule, has long exhausted its design life and accumulated various levels of accumulated damage during operation. The most common mechanism of damage to structural components of apparatuses is corrosion wear. It is caused by the exposure to aggressive corrosive fluids on metal under the combined influence of elevated pressures and temperatures. With corrosive wear, a gradual, and sometimes abrupt, decrease in the wall thicknesses of the apparatus elements occur, and their values approach unacceptable, or, as they are called, rejection thicknesses. Rejection thicknesses are the ultimate condition of the apparatus, in which their operation must be stopped and appropriate repair work on the replacement of the elements.

Corrosion wear can be detected by visual inspection and by ultrasonic measurement of thickness. Visual inspection reveals areas of corrosion wear, such as corrosion, and in the process of ultrasonic thickness gauging, wear is quantified and, based on the result, verification tests for strength are performed and the resource is predicted.
The current regulatory and technical documentation on industrial safety has established 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.

However, for a sufficiently large number of operated vessels and apparatuses, the fulfillment of diagnostic requirements is not always fully possible in terms of internal 100% visual inspection due to the original design of the apparatus, the absence of a hatch or its small diameter, etc. If it is impossible to complete internal inspection, they usually perform 100% inspection of welds with non-destructive methods and increase the number of points of ultrasonic thickness measurement.

One of the types of devices operating under conditions of corrosion wear and having an original design are devices with a shirt. The presence of a small diameter hatch on the main apparatus makes the inspection of the inner surface inadequate, and the presence of a welded shirt with small diameters makes the inspection of the outer surface of the main apparatus and the inner surface of the shirt inadequate. The most responsible structural elements of the apparatus with a shirt are shells. Both the main unit and the shirt, due to their larger area compared to other structural elements.

When conducting ultrasonic thickness gauging, such a negative fact is possible as not detecting the minimum actual thickness and performing verification strength calculations and resource estimates without taking these thicknesses into account, which will cause an overstatement of the residual resource. In addition, when assessing the actual technical condition of apparatuses with a shirt, an analysis of the formed stress-deformed state (SDS) does not occur due to the combined effect of operational loads, corrosion wear, and design features. Therefore, it is advisable to model the SDS of an apparatus with a shirt in order to identify possible adverse areas and develop the necessary technical solutions to improve reliability during operation [1-5].

2. Method of Study

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 manufactures 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 technical parameters of the device with a shirt are as follows:
- design pressure in the body $P_{\text{calc.}} = 0.6$ MPa;
- design pressure in the shirt $P_{\text{calc.}} = 0.4$ MPa;
- design temperature of the outer wall of the body under the shirt $t_{\text{calc.}} = 95$ °C;
- design temperature of the shirt body wall $t_{\text{calc.}} = 100$ °C;
- design temperature of the inner wall of the body $t_{\text{calc.}} = 90$ °C;
- medium in the body - petrochemical product;
- medium in the shirt - steam;
- diameter of the cast iron body $= 900$ mm;
- length of the cast iron body $= 750$ mm;
- wall thickness of the apparatus body $= 23\div24$ mm;
- wall thickness of the body's bonnet $= 24$ mm;
- diameter of the shirt body $= 1000$ mm;
- shirt body thickness $= 6$ mm;
- length of steel shirt body $= 605$ mm;

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.

3. Results and Discussion
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. Built model of the apparatus with a shirt.](image)

The first task of the research was to evaluate the stress-deformed apparatus with the shirt for design parameters without taking into account corrosion wear on the design wall thickness. The SDS of an apparatus with a shirt without corrosion is shown in Figure 2.

As can be seen from the figure, the maximum stresses of the apparatus with the shirt arise in the upper place of welding of the support legs on the body of the steel shirt. In addition, places of increased stress are the zones near the welding of support legs on the steel shirt body and the zone at the insertion point of the technological fittings.

Next, the SDS model of the apparatus with a shirt was modeled with the following development scenarios and the places of corrosion wear:
- continuous uniform corrosion of 0.1 mm of the inner surface of the apparatus above the shirt, and the shirt has no corrosive wear;
- continuous uniform corrosion of 0.1 mm of the inner surface of the apparatus above the shirt and continuous uniform corrosion of 0.2 mm of the inner surface of the shirt;
- continuous uniform corrosion of 0.1 mm of the inner surface of the lower belt of the shirt with a width of 100 mm, starting from the lower edge of the cylindrical body of the shirt along the entire
circumference, as one of the most unfavorable stagnant zones in the shirt due to the presence of a zone of simultaneous presence of steam and vapor condensate;
- continuous uniform corrosion of 0.1 mm of the entire inner surface of the shirt;

Figure 2. SDS of an apparatus with shirt excluding corrosion wear

Figure 3a shows the SDS of the apparatus with continuous uniform corrosion wear of 0.1 mm of the inner surface of the apparatus body above the shirt and the absence of corrosion wear on the shirt. Figure 3b shows the SDS of the apparatus with simultaneous continuous uniform corrosion of 0.1 mm of the inner surface of the apparatus above the shirt and continuous uniform corrosion of 0.2 mm of the inner surface of the cylindrical body and the elliptical bottom of the shirt [9-16].

Figure 3. SDS of the apparatus with a shirt for various variants of uniform continuous corrosion wear of the apparatus and shirt: a) - SDS of the apparatus with continuous uniform corrosion wear of 0.1 mm of the inner surface of the apparatus above the shirt and the absence of corrosion wear on the shirt b) - SDS of the apparatus with simultaneous continuous uniform corrosion of 0.1 mm of the inner surface of the apparatus above the shirt and continuous uniform corrosion of 0.2 mm of the inner surface of the cylindrical body and the elliptical bottom of the shirt
As it can be seen from the figure, in the above scenarios, the maximum stresses become somewhat less than when modeling the SDS of an apparatus with a shirt without taking into account corrosion wear. Moreover, the highest stresses equal to 119.5 MPa arise when the body of the device is located above the shirt and is not exposed to the working medium located directly in the shirt. Figure 4a shows the SDS of the apparatus with uniform continuous corrosion wear of 0.1 mm of the shirt along the belt of the inner surface with a width of 100 mm along the entire circumference, starting from the lower edge of the cylindrical body of the shirt. Figure 4b shows the SDS of the apparatus with uniform continuous corrosion of 0.1 mm of the entire inner surface of the shirt.

Analyzing Figures 3a and 3b it can be seen that in both cases the deformation of the bottom of the shirt occurs. With continuous corrosion wear of 0.1 mm of the shirt along the belt of the inner surface with a width of 100 mm, the maximum stresses increase to 179.2 MPa, and with uniform continuous corrosion wear, the entire inner surface of the shirt is reduced to 78.13 MPa. To protect the shirt of the apparatus from possible deformations and reduce the maximum acting stresses, a constructive decision was made to use a stiffening ring. 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 was modeled in order to give additional rigidity. The stiffness ring is an angle of 15 × 15 × 4 mm in size made of carbon steel of ordinary quality St3. Figure 5 shows the shirt of the apparatus in a section with a welded ring of stiffness.

Figure 4. SDS of the apparatus with a shirt for various options for uniform continuous corrosion wear of the shirt body: a) SDS of the apparatus with uniform continuous corrosion wear of 0.1 mm of the shirt along the belt of the inner surface with a width of 100 mm along the entire circumference, starting from the lower edge of the cylindrical body of the shirt; b) SDS of the apparatus with uniform continuous corrosion of 0.1 mm of the entire inner surface of the shirt.

The results of calculating the SDS of the apparatus with a stiffening ring on the inside of the shirt are shown in Figure 6.
Figure 5. Sectional shirt with welded stiffening ring

Figure 6. Results of calculating the SDS of apparatus with a stiffening ring on the inside of a shirt

As it can be seen from Figure 5, when using the stiffness ring, visible bottom deformations from the effects of corrosion wear and operating loads are not observed, and a significant decrease in the maximum stresses in the zone of welding of the supporting legs to the shirt of the apparatus is noted.

4. Conclusions
Based on the results of modeling the SDS of a device with a shirt under various corrosion wear scenarios, the following conclusions can be drawn:
- it was found that the maximum stresses for the apparatus with the shirt become significantly higher with continuous uniform corrosion wear of 0.1 mm along the separate lower belt of the inner surface of the cylindrical body of the shirt with a width of 100 mm than with the general continuous uniform corrosion of surfaces. This point must be taken into account when diagnosing and given these areas more attention and to increase the volume of control by non-destructive methods;
- 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, taking into account its design features, the material from which it is made, the type and values of operating loads.

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