Modeling the impact of shell wall thickness thinning on the stress state

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Abstract. A large number of fire-flame-proof substances, complex technological processes, characterizes oil and gas industry. Ensuring safety and preventing accidents are important issues for oil and gas industry. Modeling in modern software systems contributes to assessing the current situation and making the right decisions to extend safe operation life and increase equipment reliability. The wall thickness of a shell, even before putting in operation, is differential. In this paper, the effect of shell wall thickness thinning on the stress state is considered, taking into account the possible permissible deviation within the limits of GOST. The purpose of research is to prove the necessity and importance of taking into account uneven distribution of wall thickness for calculations. The object of study is cylindrical shell made from steel 09G2S. The thinning zone varied along the length of the study object. According to calculations result in SolidWorks software package, thinning, within the permissible possible deviation, at low pressures does not pose a danger. In case of increase in pressure up to 6 MPa and above, which is often used in complex technological processes, it leads to stress increasing in shell wall, which can contribute to strength characteristics deterioration. The results of research emphasize the importance of taking into account all features of a research object in 3D modeling, because it is at the heart of a new promising method of production management, like a digital twin.

1. Introduction

A large number of fire-flame-proof substances, complex technological processes, high accident rate are characterizing oil and gas industry. Many complex technological processes are carried out at high pressure, temperature, it increases the risk of an accident. Often, accidents occur due to emissions and leaks of hazardous substances that destroy the natural environment and negatively affect the social. Such situations should not be observed in any country in the world, safety and responsibility to nature and people should be the key moment in development of any industry. In Table 1 are shown types of hydrocarbon systems and approximate mass of their one-time circulation in technological units (for a plant with a capacity of up to 12 million tons per year).
Table 1. Types of hydrocarbon systems and approximate mass of their one-time circulation in technological units (for a plant with a capacity of up to 12 million tons per year).

| Type of hydrocarbon systems | Mass [thousand tons] |
|----------------------------|----------------------|
| compressed gas             | 21                   |
| residue                    | 29                   |
| diesel or kerosene         | 58                   |
| petroleum                  | 85                   |
| liquefied gas              | 2                    |
| gasoline                   | 36                   |

Most of equipment at facilities of Russian Federation oil and gas complexes were put into operation in the 50s of the last century, which indicates that equipment is worn out and has a large number of defects. Defects accumulate, technological processes become more complicated, which greatly affect strength characteristics and bearing strength of equipment [1, 2].

Based on statistics the following factors, lead to accidents:

- unsatisfactory condition of equipment;
- corrosion;
- thinning of wall thickness;
- violation of industrial safety requirements;
- human factor [2].

In general, technical condition of Russian oil refineries can be characterized by:

- high degree of deterioration (average level of equipment depreciation reaches 80%, and their service life exceeds possible limits);
- using outdated, energy-intensive and environmentally imperfect technologies;
- lack of funds for renewal / modernization of equipment and the need to reduce the cost of repair and maintenance;
- irrational organization of maintenance and repair of equipment, the use of an outdated system of maintenance and repair [3].

It is important to prevent accidents and incidents at the stage of defect formation, to prevent their development and consequences, to choose the most acceptable scenario for further actions, to extend safe operation resource and to increase reliability of an equipment. [4]

Monitor of an equipment state based on modeling in software programs and stress state assessment. The zone with a thinning of a shell wall thickness, which is under study in this paper, is a zone of increased stress, respectively, the likelihood of other defects as a crack creation increases.

2. Experimental Section

Thinning of the wall thickness usually occurs due to corrosion and erosion. In oil refining, aggressive substances, complex technological processes using high temperatures and pressures have a particular impact.

Usually in oil and gas industry, carbon and alloyed chromium steels are used. Some materials are more stable, like 20X13, and unstable, like St.3 and 09G2S. Despite this, even non-resistant materials are widely used in mechanical engineering, but they require adequate corrosion protection. For example, for corrosion protection in formation water St. 3 and chromium steel apply cathodic electrochemical protection. In addition, the use of dissimilar metals can lead to increased corrosion of one of them. In welded joints and in heat-affected zones, pitting corrosion can develop, which in turn can lead to through destruction of the metal. [5]
Particular attention should be paid to cumulative effect of defects like buckle and metal loss, this contributes to uneven distribution of properties. Defects are detected during periodic technical examination of equipment. The most commonly used method of non-destructive testing for this purpose is ultrasonic testing and thickness measurement.

Today, different computer programs allow you to create a logical, safe layout of enterprises, effective technological blocks, allow you to remotely monitor operation of installations, plan and carry out joint work of specialists, monitor technical condition of equipment, which significantly increases efficiency, reduces errors, and thus increases reliability and safety. It improves work of an engineer and at the same time makes it easier. With cloud technologies, the Internet of Things, Big Data and artificial intelligence, the role of virtual space becomes extremely important, the interaction of physical world and the virtual becomes more effective [6].

Modern software systems allow you to study necessary properties and behavior of a research object, and adapt the real object according to computer modeling results. Today special attention is paid to digital twins. These are systems consisting of real objects, virtual representatives and controllers.

The value of a digital twin lies in the ability to track the behavior and state of an observation object, to adjust the product with minimal financial costs in accordance with market requirements, to determine the most favorable operating conditions and modes in accordance with equipment actual state.

In oil and gas industry, it is possible to use a digital twin for the following purposes:
- remote monitoring and control over a processes course;
- production process management;
- production optimization;
- equipment breakdown detection;
- planning of repair works;
- ensuring industrial safety;

A promising area of digital twin application is maintenance of an object throughout its entire life cycle. Managing big data generated during a product lifecycle is the most critical step that can provide insight and valuable information to guide production, service and repair issues. Despite the fact that now a large amount of information can be obtained through sensitive sensors, for example, in complex diagnostic monitoring, nevertheless, information at different stages is isolated, partially obtained, which does not lead to fully effective use and correct assessment of the state. At different stages of life cycle, the virtual twin is used to collect information in real time in various forms (Tables, pictures, graphs, videos, and so on) and turns them into a single representation, a digital asset.

With the digital twin, each physical object owns one unique digital model, the so-called digital shadow, in a very realistic 3D form to detail and analyze its performance, which can provide real-time insight, early warnings, predictions and ideas for optimization.

Calculation of any observation object stress state allows you to determine possible weak points of equipment. For such purposes, software systems based on finite element method are most often used. This method is widely used to solve problems in mechanics of deformable body. The most widely used are SolidWorks, Abaqus, Ansys and others. In this paperwork, calculations were carried out in SolidWorks software package [7].

Even from the factory, tube thickness is uneven due to various reasons. The slightest deviations in geometric parameters, such as ovality, uneven thickness within the GOST limits, lead to a significant change in a shell wall overall stress pattern. Carrying out strength calculations on models that do not take into account such design features leads to calculation errors. At the stage of maintenance and repair work, such information is essential. Places of stress concentration, in turn, may indicate a liability to defect formation.

Similar situation should be taken into account during operation, since in combination with other defects it can affect the strength characteristics. When creating a digital twin, a modern method of production management, taking into account such features can be an excellent assistant in solving of extending safe operation resource issue.
3. Object of Study
In this paper, the design model is considered as cylindrical shell made of 09G2S steel with an outer diameter of 108 mm and a wall thickness of 6 mm. The length of the cylindrical part, bounded on both sides by blank flange, is 800 mm. The cylindrical shell is made in accordance with GOST 32678-2014, black flanges are Ø108 × 8 mm in accordance with GOST 17379-2001. The yield stress is 295 MPa. [8]

Figure 1 shows the model of investigated shell built in the SolidWork software package.

Deviation of wall thickness even within the permissible range can significantly affect the stress state. In this paperwork work, deviations of shell wall thickness by maximum allowable value of 1.08 mm were modeled, the thickness in the thinning zone was 4.92 mm. Remaining sections were taken 7.08 mm, that is, with the maximum allowable deviation in the positive direction. In each calculation, shell was loaded with internal pressure, up to the yield stress [8-11]

In addition, it is important to determine influence of thinning zone size which is located by rings. The defect zone varied along the length of cylindrical part from 0 to 100% of surface area.

4. Results and Discussion
The results obtained for a number of loading of the shell with different thinning section area are presented in Table 2.

![Figure 1. The model of investigated shell.](image)

**Table 2. Results of shell loading with thinning section different areas.**

| Loading pressure, P [MPa] | Maximum stress [MPa] (depending on the metal thinning section area, in% of the length) |
|--------------------------|------------------------------------------------------------------|
|                          | 0%                  | 15%                | 30%                | 45%                | 60%                | 75%                | 90%                | 100%               |
|                          | 0.01                | 0.179058           | 0.176214           | 0.176167           | 0.176155           | 0.17624            | 0.176233           | 0.176151           | 0.202357           |
|                          | 1.5                 | 23.7174            | 26.4321            | 26.425             | 26.4232            | 26.436             | 26.4349            | 26.4227            | 30.3536            |
The graphic dependence of maximum stresses on thickness thinning under pressure loading is shown in figure 2.

![Graphical dependence of maximum stress on thickness thinning under pressure](image)

**Figure 2.** Graphical dependence of maximum stress on thickness thinning under pressure, where the thinning area is indicated on the right column, as a percentage of the total area.
5. Conclusion

There are following conclusions which were obtained as a result of loading:

- the dependence of stress and pressure is directly proportional;
- the stress arising in the shell wall, by low pressure, even with a thinning area equal to 90% of total surface area, did not change stress value significantly, the difference in indicators was 0.023 MPa;
- at high pressures equal to 6 MPa and higher, which is used in such technological processes as hydrocracking, the stress changes significantly. Compare stress values of wall thinning of 15% and 100% at a pressure of 6 MPa, the stress jump was 16 MPa, at a pressure of 15 MPa - 39 MPa. Compare stress values of wall thinning of 0% and 15% at a pressure of 6 MPa, the stress jump was 11 MPa, at a pressure of 15 MPa - 27 MPa. These calculations were carried out with shell thinning within acceptable limits, and without taking into account additional defects, metal corrosion, and so on, but even such stress increases should be considered when making decisions.

The modern concept of an equipment digital twin is a promising method of production management. The twin, in turn, is based on a 3D model of an object that exactly repeats the geometry, features and existing defects. Developing and aging in parallel with the real object, the virtual twin allows you to correctly assess the actual state of the equipment. The results of the study proved that during creating a digital twin, it is necessary to take into account the inhomogeneity of the wall thickness within the permissible limits, since even without any additional defects, corrosion, this affects the general stress state.

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