Evaluation of the stressed-deformed condition of the cylindrical shell of the separator under corrosion wear

A V Rubtsov, Z R Mukhametzyanov, P A Kulakov and K S Arkhipova
Ufa State Petroleum Technological University, 1, Kosmonavtov street, Ufa, 450062, Russia
E-mail: kulakov.p.a@mail.ru

Abstract. Separators are operated at elevated working pressures and temperatures, as well as the simultaneous presence of liquid and gaseous working media that have an aggressive effect on the metal. With the combined action of workloads and exposure to a corrosive environment during operation, the development of defects such as general corrosion, stress corrosion cracking, ulcerative corrosion, etc. In order to determine the technical condition of the apparatus, the main mechanism of damage of which is corrosion, it is necessary to measure wall thicknesses, the minimum value of which is regulated by the current regulatory and technical documents on industrial safety. The presence of such uncontrolled areas does not fully provide a reliable picture of the assessment of the technical condition, and the actual stress-strain state of the entire shell is not taken into account, depending on the design of the apparatus, the presence and location of process fittings, the degree of corrosion wear, etc. In this paper, we study the relationship between the impact of operational loads, the influence of technological fittings on the stress-strain state of the cylindrical shell of the separator during its corrosion wear.

1. Introduction
At hazardous production facilities, which include oil and gas refineries, a large amount of equipment is operating under excessive pressure [1-4]. A significant part of this equipment has long developed its design resource and is both morally and physically obsolete. A special influence on this circumstance is exerted by corrosion-erosion wear due to the influence of aggressive working environments under operating pressures and temperatures [5-6]. Due to corrosion, a gradual degradation of the equipment metal occurs, which inevitably leads to the ultimate state of structural elements due to unacceptable thinning of the wall [7-9]. One of the types of equipment operating under conditions of corrosive wear are separators. The simultaneous presence of liquid and gaseous phases inside the apparatus creates the prerequisites for possible intensive wear. As a rule, such methods as visual and measuring control and ultrasonic thickness gauge are used to qualitatively and quantitatively assess the degree of wear [10-11]. For visual and measuring control, the areas and type of corrosion are determined, and for ultrasonic thickness measurement, a quantitative assessment of wear occurs, which subsequently serves as the main information for the strength calculation and assessment of the residual life. The most responsible, both in terms of operation and in terms of technical diagnosis is the cylindrical shell of the separator. Due to the large surface area, its 100% examination for corrosion wear and thinning of the wall is not possible. Also, an obstacle to full control may be, for example, the physical
impossibility of inspecting and measuring some places, operating conditions, the presence of internal
devices, insulation, etc.

The current regulatory and technical documentation on industrial safety has established the
following 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 generatrix of the shell and four radii of the bottoms
  through 90° around the circumference of the element. At each shell side of the vessel, at least
  three measurements are made for each generatrix (in the middle and at the edges).

Moreover, if you are guided by the above minimum requirements, then on the shell of the case
there are enough only a total of 12 measurement points, which is disastrously small in certain cases to
conduct a reliable assessment of the technical condition, calculations and forecasting of the resource.

It is possible to develop such an unfavorable scenario as not detecting the minimum thickness in
reality due to the presence of uncontrolled sections and making calculations without taking these
thicknesses into account, which will cause an overstatement of the further term of safe operation [12].

Also, when assessing the actual technical condition of the apparatus, the formed stress-strain state
(VAT) is not analyzed due to the impact of operational loads, corrosion wear and structural features
[13].

Therefore, it is advisable to consider the impact of the above parameters on the VAT of the
cylindrical shell of the separator in order to identify adverse areas and their constant monitoring during
routine inspections of the technical condition [14-15].

2. Research methodology

To conduct a study of the relationship between the impact of operational loads, the effect of the
location of technological fittings on the VAT of the cylindrical shell of the separator during its
corrosion wear, a separator of one of the oil and gas processing plants was selected. The separator
shell material is high-quality carbon steel 20.

The technical parameters of the separator are as follows:

- design pressure \( P_{\text{calc}} = 2.0 \text{ MPa} \);
- design temperature \( t_{\text{calc}} = 20 \degree \text{C} \);
- working environment - ammonia.

The separator is a vertical welded vessel, consisting of a cylindrical shell of the body, elliptical
bottoms, technological fittings and is mounted on supporting posts (legs). The separator is designed to
separate liquid ammonia from gaseous.

Due to the fact that the working medium in the separator is ammonia, there is a possibility of
corrosion cracking of the inner surface of the separator. In this regard, the VAT separator was
simulated with the search for the so-called “problem” plots.

In the process of research, 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 you to perform modeling in solving
strength and thermal problems. The procedure is performed in three stages:

- the adoption of a method of fixing and the application of existing loads and temperatures;
- creating a finite element mesh, its optimization according to various criteria;
- execution of the calculation.
The calculation results are presented in the form of a map. Parameters such as loads, displacements, deformations, fatigue and others are displayed. At the same time, VAT can be considered both as a whole and in different axes.

The APM FEM system allows you to create a report that displays all accepted modeling conditions, finite element mesh parameters, material characteristics, as well as visualization of the results. For subsequent analysis, you can create screenshots for use in reports and publications.

An ultrasonic thickness measurement of the main structural elements of the separator was also carried out during the next technical diagnosis and the minimum values of wall thicknesses were obtained with an indication of their location.

Table 1 shows the data of ultrasonic thickness measurement of the cylindrical shell of the separator.

| Number of the point | Design thickness, mm | Measured thickness, mm | Number of the point | Design thickness, mm | Measured thickness, mm |
|--------------------|----------------------|------------------------|--------------------|----------------------|------------------------|
| 1                  | 12.0                 | 11.7                   | 9                  | 12.0                 | 12.1                   |
| 2                  | 12.0                 | 11.5                   | 10                 | 12.0                 | 12.1                   |
| 3                  | 12.0                 | 12.1                   | 11                 | 12.0                 | 12.3                   |
| 4                  | 12.0                 | 12.0                   | 12                 | 12.0                 | 12.0                   |
| 5                  | 12.0                 | 11.5                   | 13                 | 12.0                 | 11.5                   |
| 6                  | 12.0                 | 12.2                   | 14                 | 12.0                 | 10.8                   |
| 7                  | 12.0                 | 11.9                   | 15                 | 12.0                 | 11.0                   |
| 8                  | 12.0                 | 12.1                   | 16                 | 12.0                 | 10.9                   |

At the first stage, a separator model 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 the stress-strain state (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.

The separator model is shown in the figure 1.

3. Research results and discussion

The first objective of the research was to evaluate the VAT of the cylindrical shell of the separator for the design parameters without taking into account corrosion wear on the design wall thickness \( s_{\text{design}} = 12.0 \text{ mm} \). The VAT of the cylindrical shell of the separator without taking into account corrosion wear is shown in figure 2.

As can be seen from the figure, the maximum stresses of the cylindrical shell of the separator occur at the insertion points of the technological fittings, as well as in the area above the hatch between the fittings in the upper part of the shell.

Then, the VAT simulation of the separator shell was carried out taking into account the measured wall thicknesses during technical diagnostics. The places of thinning and measurement values were selected according to table 1. Figure 3 shows the stress-strain state of the cylindrical shell of the separator, taking into account corrosion wear.

As can be seen from the figure, a rather long region of maximum stresses of the cylindrical shell of the separator is concentrated in the same zone above the hatch between the fittings in the upper part of the shell corresponding to measuring points No. 5-8 with a minimum measured thickness of 11.5 mm, and not the lower section of the shell, corresponding to measuring points No. 13-16 with a minimum measured thickness of 10.8 mm.

It is of interest to simulate the separator at various design pressures and temperatures with the aim of analyzing the VAT of the zone mentioned above when the pressure and temperature change.
Figure 4 shows, as an example, the VAT of the cylindrical shell of the separator, taking into account corrosion wear with different pressures and temperatures.

Figure 1. Model of the separator.

Figure 2. VAT of the cylindrical shell of the separator excluding corrosion wear.

Figure 3. VAT of the cylindrical shell of the separator, taking into account corrosion wear.
Figure 4. VAT of the cylindrical shell of the separator, taking into account corrosion wear with different pressures and temperatures: a) - VAT of the cylindrical shell of the separator, taking into account corrosion wear at a design pressure of 2.1 MPa, design temperature 20 °C; b) - VAT of the cylindrical shell of the separator, taking into account corrosion wear at a design pressure of 2.2 MPa, design temperature 20 °C; c) - VAT of the cylindrical shell of the separator, taking into account corrosion wear at design pressure 1.9 MPa, design temperature 100 °C; d) - VAT of the cylindrical shell of the separator, taking into account corrosion wear at a design pressure of 1.8 MPa, design temperature 150 °C; e) - VAT of the cylindrical shell of the separator, taking into account corrosion wear at a design pressure of 1.7 MPa, design temperature 200 °C.

As it can be seen from figure 4, the determining parameter for the formation of the zone of maximum stresses is the internal overpressure. With an increase in the design pressure, in the area above the hatch between the fittings in the upper part of the shell, the stress values increase and the area on which they act expands. When pressure decreases and temperature rises, stresses in this zone decrease.

The next step in the research was to establish the relationship between the location of technological fittings for the occurrence of a zone of increased stresses on the cylindrical shell of the separator body at a design pressure of 2 MPa and a design temperature of 20 °C, taking into account corrosion wear. Examples of VAT with different configurations of process fittings are shown in figure 5.
Figure 5. Examples of VAT with different configuration of technological fittings at a design pressure of 2 MPa and a design temperature 20 °C considering corrosion wear: a) - VAT of the cylindrical shell separator (the upper fittings on the body shell are shifted down closer to the hatch); b) - VAT of the cylindrical shell separator (the upper fittings on the shell of the housing are shifted up closer to the lower bottom); c) - VAT of the cylindrical shell separator (there are no top fittings on the body shell); d) - VAT of the cylindrical shell separator (there are no upper fittings on the body shell, the hatch is shifted upwards to the upper bottom); e) - VAT of the cylindrical shell separator (the hatch is shifted up to the upper bottom); f) - VAT of the cylindrical shell separator (the hatch is shifted to the center of the cylindrical shell of the separator).

As it can be seen from figure 5, the determining moment for the formation of maximum stresses in the cylindrical shell of the separator body is the location of the hatch with a nominal diameter of 400 mm. Moreover, the worst option is achieved with the option if the hatch is located in the upper part of the shell of the separator.

4. Conclusion
After the research on the interconnection of the impact of operational loads, the effect of the location of technological fittings on the VAT of the cylindrical shell of the separator during its corrosion wear as a result of calculations performed by the APM FEM system, the following conclusions can be made:
it was found that corrosion wear does not significantly affect the VAT of the cylindrical shell of the separator and the formation of zones of maximum stresses, and the design of the fittings has a greater influence, which must be considered when assessing the actual technical condition of the object. In this regard, it is necessary to subject these areas to 100% diagnosis by non-destructive testing methods during periodic diagnosis in order to timely detect unacceptable deviations;

• it is shown that the determining parameter of stress growth in the simulation of the separator VAT is an increase in internal overpressure, and not an increase in temperature;

• it was revealed that the zone of maximum stresses when modeling the VAT of the cylindrical shell of the separator under the influence of operational loads during corrosion wear depends on the location of the process fittings and, to a greater extent, the hatch with a nominal diameter of 400 mm.

References
[1] Abhilash J and Apeksha Acharjee B 2018 IOP Conference Series: Materials Science and Engineering 455(1) 012113
[2] Bakhtizin R N, Mustafin F M, Bykov L I, Khasanov R R and Kunafin R.N. 2016 SOCAR Proceedings 3 52-8
[3] Ulrich T, Gabriel A A, Ampuero J P and Xu W 2019 Nature Communications 10(1) 1213
[4] Khabibullin M Y and Sidorkin D I 2016 SOCAR Proceedings 3 27-32
[5] Kulakov P A., Kultubulatov A A and Afanasenko V G 2018 SOCAR Proceedings 2 41-8
[6] Song G, Li Y, Wang W, Jiang K, Shi Z and Yao S 2018 Chemical Engineering Science 192 477-87
[7] Goto H, Kaneko Y, Young J, Avery H and Damiano L 2019 Scientific Reports 9(1) p. 1117
[8] Tropkin S N, Tlyasheva R R, Bayazitov M I and Kuzeev I R 2018 IOP Conference Series: Materials Science and Engineering 327(4) 042012
[9] Mirkhaydarova K A, Tyusenkov A S and Rizvanov R G 2018 Solid State Phenomena 284 1297-301
[10] Faritov A T, Rozhdestvenskii Y G, Yamshchikova S A, Minnikhanova E R and Tyusenkov A S 2016 Russian Metallurgy (Metally) 11 1035-41
[11] Kuzeev I R, Naumkin E A, Pankratiev S A and Tlyasheva R R 2018 Solid State Phenomena 284 587-92
[12] Tyusenkov A S, Rubtsov A V and Tlyasheva R R 2017 Solid State Phenomena 265 868-872
[13] Buzzylo V, Pavlychenko A, Savelieva T and Borysovska O 2018 E3S Web of Conferences 60 00013
[14] Mukhamedzyanov Z R, Rubtsov A V and Valiev A S 2019 Lecture Notes in Mechanical Engineering 0(9783319956299) 1999-2006
[15] Kovshova Y S, Kuzeev I R, Naumkin E A, Makhutov N A and Gadenin M M 2015 Inorganic Materials 51(15) 1502-7