The influence of aggressive environmental factors on the corrosion-mechanical wear and the risk of depressurization of oil field pipelines

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Abstract. The work is devoted to assessing the risk of depressurization of field pipelines operating under the conditions of the combined action of a corrosive environment and mechanical impurities. For a comparative assessment of the contribution of the corrosion factor to the fracture process, studies have been carried out on the development of corrosion processes on 20A and 09G2S steels in field media of different aggressiveness. The rate of destruction of the pipe metal under the influence of mechanical impurities was studied using the adapted ASTM G65 methodology, which makes it possible to evaluate the complex effect of corrosion and mechanical factors. Based on the data obtained during the study, equations were derived that characterize changes in the corrosion rate depending on the value of the hydrogen index (pH), degree of mineralization, CO2 content and temperature of the production medium and the content of solids. Using the obtained dependences, a methodology was developed for predicting the risk of depressurization of field pipelines depending on the composition of the transported medium and the dynamics of its change during field development. Application of the developed methodology will allow assessing the risks of depressurization under the influence of corrosion-mechanical factors in the design of oil field pipelines.

1. Introduction

Field pipelines during operation are subject to a wide range of negative factors affecting their longevity; therefore, assessing their service life and the risks of failure is a complex multi-factor task. Of the groups of negative risk-forming events specified in SP 366.1325800.2017 [1], the most common causes of depressurization of field pipelines are associated with the corrosion-mechanical effect of the produced products [2, 3]. A generalization of the most aggressive factors of field media acting on the inner surface of pipelines is shown in figure 1.

The aim of this work was to develop an experimental-calculation methodology for predicting the risk of developing internal general and local corrosion of field pipelines depending on the physicochemical composition of the pumped medium.
2. **Methodology for experimental research**

For research, the most common grades of steel 20A and 09G2S were selected. The laboratory testing program included determining the stability of the studied steels in aqueous solutions with a different range of the following indicators:

- **pH** - from 8.0 to 5.0,
- salinity from 0 g / l to 40 g / l,
- CO2 content from 0 to 300 mg / l,
- temperature from +20 °C to +80 °C,
- the content of solids from 0 to 10 g / l.

The determination of corrosion resistance was carried out by the gravimetric method according to GOST 9.905-2007. The samples were tested by holding at a fixed temperature in a solution with a given NaCl concentration, pH, and gas content for 336 hours. After exposure, the change in sample weight was evaluated. According to the data obtained and the area of the samples, the corrosion rate in mm / year was determined.

Determination of resistance to corrosion-mechanical wear was carried out according to an adapted method according to ASTM G65 [4]. The method of corrosion-mechanical testing consisted in feeding an abrasive into the friction zone of a rubber wheel over a metal sample in the presence of a corrosive medium of a given composition. As components for the preparation of simulation media, tap water purified by reverse osmosis, silica sand M6 (SiO2 0.2 mm), reagents HCl, Na2CO3, NaCl were used. When evaluating the results of corrosion-mechanical wear, the contribution of the contact area to the change in the weight loss indicators was determined by measuring the wear zone on the InfinitFocus G5 and Alicona topography measuring instruments.

To calculate the corrosion rate and corrosion-mechanical wear, an approach was used based on a fractional factor experiment, planned on the basis of 5 variable factors. As an assumption, it was suggested that the corrosion process can be described by a linear model in the selected ranges of variation. The obtained dependences of the change in the corrosion rate on the degree of aggressiveness of the field medium were used to assess their contribution to the probability of depressurization of the field pipeline according to the following relationship:

$$P = \frac{V_{cor}T}{S_{nom}}$$

where: T - the duration of operation, years, Snom - nominal pipe wall thickness, mm.
3. Research results and discussion

Based on the values of the mass loss of the samples obtained during testing in different environments, the values of the corrosion rate and corrosion-mechanical wear, calculated in figures 2 and 3, were calculated.

**Figure 2.** Histogram of corrosion rate values for 20A steel in different test environments.

**Figure 3.** A histogram of corrosion rate values for 09G2S steel in different test environments.

Using the obtained experimental data, dependences were derived for calculating the corrosion rate of the studied steels in media of different compositions:

- for steel 20A:
  
  \[ v_{\text{cor}} = 0.041 + 0.0093(8.0 - p H_{\text{cp}}) - 0.00036(S_{\text{cp}}) + 0.002(T - 20) + 0.00034q(CO_2) \]  
  
  \[ (2) \]

- for steel 09G2S:
  
  \[ v_{\text{cor}} = 0.043 + 0.010(8.0 - p H_{\text{cp}}) - 0.00033(S_{\text{cp}}) + 0.0022(T - 20) + 0.00056q(CO_2) \]  
  
  \[ (3) \]

where: \( pH_{\text{av}} \) - the hydrogen indicator, \( S_{\text{av}} \) - the degree of mineralization, g / l; \( T \) - temperature, 0C; \( q(CO_2) \) - carbon dioxide content, mg / l.

From the values of the wear rate of the samples, the following equations were obtained to determine the contribution of the corrosion-mechanical factor:

- for steel 20A
  
  \[ v_{\text{cor} - m} = (-0.0604 \times pH + 2.832) \times N \times \omega_{\text{abr}} \]  
  
  \[ (4) \]

- for steel 09G2S
  
  \[ v_{\text{cor} - m} = (-0.0012 \times pH + 1.882) \times N \times \omega_{\text{abr}} \]  
  
  \[ (5) \]

where: \( N \) is the concentration of abrasive, %; \( \omega_{\text{abr}} \) - flow velocity, m / s.

The obtained equations make it possible to estimate the probability of depressurization of a production pipeline for media of different aggressiveness [5]. For example, figure 4 shows the combined diagrams for steel 20A, combining the influence of various factors, calculated on the basis of the actual life of the pipeline for 10 years.
Figure 4. Change in the probability of failure of steel 20A after 10 years of operation depending on the level of aggressive factors in the production environment: a) with a salinity of 30 g / l at different pH values without mechanical impurities; b) at different pH values with different contents of mechanical impurities at a speed flow 0.25 m / s.

Analysis of the presented diagrams shows that the probability of failure due to corrosion of the production pipeline with a 10-year service life in contact with the production medium with a pH of 8.0 and a degree of mineralization of 10 g / l at a temperature of +60 °C will be 27.6%. When substantiating the choice of material execution of a pipeline with such a probability of failure, expensive solutions for corrosion protection can be abandoned. But the presence in the commercial environment of mechanical impurities in an amount of 3 g / l will increase the likelihood of failure by 29.4%. Thus, the total probability of failure of such a pipeline will be 57%, which will require the adoption of design and technological solutions for additional protection of the inner surface of the pipes from corrosion and mechanical damage.

Tables 1 and 2 show the probabilities of depressurization of pipelines made of steel 20A and 09G2S with a nominal wall thickness of 6.0 mm due to the development of corrosive and corrosion-mechanical processes in environments with different levels of aggressive factors.

Table 1. The probability of depressurization of the production pipeline as a result of the development of corrosion depending on the duration of operation on the example of steel 20A.

| Failure Options              | Service life, years |
|------------------------------|---------------------|
|                              | 1  | 2  | 4  | 6  | 8  | 10 |
| The composition of the medium|     |    |    |    |    |    |
| pH 7, salinity 30 g / l, temperature +60 °C, CO₂ content 300 mg / l |     |    |    |    |    |    |
| The probability of failure during corrosion tests, % | 19.0 | 38.0 | 76.0 | | Depressurization | |
| The composition of the medium |     |    |    |    |    |    |
| pH 8, flow rate 2.35 m / s, abrasive concentration 1 g / l |     |    |    |    |    |    |
| The probability of failure during corrosion-mechanical tests, % | 9.2 | 18.4 | 36.8 | 55.2 | 73.6 | 92 |

Table 2. The probability of depressurization of the production pipeline as a result of the development of corrosion, depending on the duration of operation, for example, steel 09G2S.

| Failure Options              | Service life, years |
|------------------------------|---------------------|
|                              | 1  | 2  | 4  | 6  | 8  | 10 |
| The composition of the medium |     |    |    |    |    |    |
| pH 8, flow rate 2.35 m / s, abrasive concentration 1 g / l |     |    |    |    |    |    |
| The probability of failure during corrosion-mechanical tests, % |     |    |    |    |    |    |
As can be seen from the data presented, the presence of such aggressive factors as the content of carbon dioxide and mechanical impurities can lead to depressurization of a pipeline that has not exhausted its life. Using the proposed dependencies for assessing the corrosion rate and analyzing the probability of failures at the design stage will make it more reasonable to make decisions on the material and structural performance of individual sections of field piping networks.

4. Conclusions
An experimental-calculation methodology has been proposed for predicting the risk of developing internal general and local corrosion of field pipelines depending on the physicochemical composition of the pumped medium and the content of solids.

Based on the results of laboratory studies, the dependences of the corrosion rate on steels 20A and 09G2S were obtained, which estimate the contribution of such parameters as the hydrogen index, degree of mineralization, temperature of the medium, and carbon dioxide content.

An experimental approach is proposed for assessing the contribution of mechanical impurities to the rate of corrosion-mechanical destruction of the inner surface of pipes based on the adapted ASTM G65 methodology.

References
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