Composite tube damage evaluation in aggressive oil-gas field

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Abstract.
The purpose of this article is to lead a research program to assess the damaging of liners of a composite tube for operation in oil-gas fields containing carbon dioxide, including those with minor amounts of hydrogen sulfide at standard conditions and under conditions of elevated temperature and pressure. To assess the level of corrosion resistance of the composite tube liner, stress corrosion cracking tests were carried out, autoclave tests for general corrosion at elevated temperatures and pressures were also carried out, and electrochemical studies were carried out to assess the equilibrium corrosion potential and calculate corrosion rates analyzing Tafel curves.

1. Introduction
Steel tubing used in modern conditions of oil-gas fields suffer of severe wear as a result of the complex aggressive effects of recovered elements: hydrogen sulfide, carbon dioxide, oxygen, highly mineralized oilfield water, various types of bacteria, solid suspended particles and other aggressive components, included in the extracted products [1–3, 6–10]. In difficult production conditions the serviceability of tubing is several times lower than the declared service life of the pipe manufacturer. The number of premature tubing failures due to internal corrosion is significant (failures of more than 50%), which leads to a multiple increase of production cost [4]. Traditionally low alloyed steel pipes are used in the oilfield due to their low cost. However the low corrosion resistance of such pipelines dictates the need to improve their performance using various approaches. Due to their high cost, the use of high alloyed steel is not always economically reasonable. The use of inner covering, both non-metallic [12] and metallized [11], is widely used. The main disadvantages of non-metallic (polymer) coatings are the number of operational limitations (on the operating temperature and pressure in the system, resistance to chemically aggressive components, the contamination in the extracted product), as well as the lack of in-line inspection technology to predict their service life. [13]. The use of internal metallized coatings on tubing pipes, a relatively new and not yet very common technology in the Russian Federation - is an economically promising method of protection provided a thin coating is applied, however, the limitation of the use of this type of coating is connected with a high cost comparing to non-metallic (polymer) coatings, with the limited areas of application, as well as with the limited possibility of coating long pipes [5, 14].
One of the effective ways to multiply the operating life of tubing without a significant cost increase is the protection technology, where a stainless steel insert coating is used as an inner layer [15].
The purpose of this article is to lead a research program to assess the damaging of liners of a composite tube for operation in oil-gas fields containing carbon dioxide, including those with minor amounts of hydrogen sulfide at standard conditions and under conditions of elevated temperature and pressure.

2. Materials and experiment method

Samples for research were made of a composite tube pup joint. The inner part of the tubing (insert) is made of 15H13N2MB steel with a thickness of ~1 mm. The material for the inner layer (60x1.0 mm size pipe) was gained by 4 times rolling of cold (warm) deformation from a rerolling material 108x8.0 mm from originally produced metal, followed by heat treatment.

To assess the level of corrosion resistance of the composite tube liner, stress corrosion cracking tests were carried out, autoclave tests for general corrosion at elevated temperatures and pressures were also carried out, and electrochemical studies were carried out to assess the equilibrium corrosion potential and calculate corrosion rates analyzing Tafel curves.

The cladding liability to stress cracking in H2S was assessed in accordance with the requirements of NACETM 0177, Method C. Sample surface roughness was achieved manually to get the required value of 0.81 Ra. Tests of cladding layer samples were carried out at loads of 60, 70 and 80% of the actual yield limit. Tests were carried out in brine A, NACETM 0177 standard. The brine was saturated with 100% H2S. The concentration of H2S at the beginning of the tests was 2650 ppm, at the end of the tests it was 2570 ppm. The pH of the brine was 2.6 at the beginning of the test and 3.2 at the end of the test. The test lasted 720 hours.

The resistance of the composite tube liner to general corrosion at elevated pressure and temperature was evaluated by performing autoclave general corrosion tests. While testing GOST 9.905 and GOST 9.908 requirements (National state standards) were considered. Autoclave general corrosion tests were carried out on five samples with +80 °C temperature, partial pressure CO2 of 3.0 MPa and total pressure of 5.0 MPa. A water solution of 5% NaCl with 0.5% CH3COOH and a pH level in the range of 3.0 - 4.0 was chosen as a test brine. A pH level before test was 3.0, a pH level at the end of the test was 4.06. The test lasted 720 hours. As soon as the time is out, the samples were removed from the autoclave, cleaned of corrosion products, dried and weighed on an analytical scale SARTOGOSM LV 210-A with an accuracy of 10⁻⁶ g.

General corrosion rate assessment was carried out by gravimetric method according to the formula:

\[ K = 1,129 \times \frac{m_0 - m_1}{S \times \tau}, \text{mm/year} \]  

(1)

where 1,129 – coefficient for converting the dimension of the general corrosion rate of g/m² h into mm/year; m₀ – sample weight before testing, g; m₁ – sample weight after testing, g; S – sample surface area, m²; τ – test duration, h. The coefficient 1.129 is calculated taking into account the density of steels of the martensitic class of the 13Cr type, taken equal to 7.76 g / sm³, taking into account the correction factor equal to 0.989 in accordance with GOST R 53366.

To estimate the steel behavior in CO2-saturated environment and to determine the theoretical corrosion rates and their subsequent comparison with the rates obtained by other methods in accordance with ASTM G3, G5, G59, G102 standards, electrochemical studies were carried out. To conduct electrochemical studies the surfaces of the composite tube liners samples with a working area of ~ 1 cm² were polished and grinded with a diamond suspension. Then the sample was soldered to the conductor in the form of a copper wire, the other parts of the sample were isolated with a heat-resistant paint coating and the surface was degreased. The tests were carried out using a VersaPrincetonAppliedResearch potentiostat supported with specialized software. The test brine was a deaerated 5% NaCl based on distilled water with a fixed pH = 3.0. The study consisted of putting the sample in a test environment, measuring the equilibrium corrosion potential (Ecorr) for 55 min (3300 s) and carrying out subsequent linear polarization in the potential range from -100 to 100 mV with a sweep rate of 0.16 mV / s and getting a polarization curve. The theoretical corrosion rates were calculated graphically using polarization curves.

3. Research results and discussion

The results of assessing the tendency to cracking in a hydrogen sulfide-containing environment showed that all tested samples had a tendency to stress corrosion cracking in an H2S environment: at a load level...
of 60% of the actual yield strength, the samples did not fracture, however, they had longitudinal cracks, which is the evidence of the tendency to cracking under test conditions; at loads of 70 and 80% - the samples were completely destroyed (Figure 1).

![Figure 1](image1.png)

**Figure 1.** Samples after load testing: a) 60 %; b) 70 %; c) 80 %.

It was found that fracture cracks originated in the crosswise dimples appeared during pup joint production process. In addition to the main cracks, along which the destruction occurred, there are secondary cracks on the samples. Also, after testing, a large number of pitting with a diameter of ≈10 mm and metal blistering were found on the surface of all samples, which indicates local merging of chromium-nickel steel (Figure 2).
Autoclave tests have shown that the average rate of general corrosion of the composite tube liner samples at increased pressure and temperature is 0.22 mm/year; the surface of samples were merged, and there were pitting with a diameter of 100 micron (Figure 3).

The results of measuring the corrosion potential and corrosion rates in a saturated CO2 brine, T = 60°C, pH ~ 3.0 showed that the corrosion potential of the steel is practically unchanged over time, which indicates the stability of the corrosion potential of the test material in this environment (Figure 4).
During the electrochemical studies, the theoretical corrosion rate was calculated using Tafel curves. Research results showed the average theoretical corrosion rate obtained by the electrochemical method for steel 15H13N2MB under test conditions is 0.59 mm/year (Figure 5). So it has been shown that steel is actively merged under test conditions; there is no passivity.

Stress corrosion cracking tests were carried out according to the most severe scenario environment aggressiveness wise (H2S concentration, pH level), moreover, the tendency to stress corrosion cracking was increased due to the crosswise dimples on the outer surface of the liner, which are the centers of crack initiation: in actual operating conditions, the outer part of the liner will not contact with an aggressive environment, therefore, its higher resistance to corrosion cracking can be expected.

Autoclave and stress corrosion cracking tests revealed pitting on the steel surface. It is probably connected with metal electrochemical contrast which needs further investigation. It was also shown that the susceptibility of chromium-nickel steel to pitting corrosion is significantly influenced by the quality of its surface: mechanical polishing reduces the tendency to pitting at normal temperatures, while electro
smoothing increases it. Preliminary metal passivation, for example \( \text{HNO}_3 + \text{K}_2\text{Cr}_2\text{O}_7 \), increases the resistance of chromium-nickel steel to pitting corrosion.

The average general corrosion rate during autoclave tests in CO\(_2\) saturated environment was 0.22 mm/year; under the condition of proportional steel merging, such corrosion rate data will provide 4 years of operation. However, we should take into account that under real conditions, the proportional steel merging is barely possible and with H2S, the rates of general corrosion can be higher.

In other words, it was found that this steel grade has limitations in corrosion resistance. It is necessary either to limit the operating conditions, or to increase the corrosion resistance of this steel grade by changing the quality, chemical composition, etc.

4. Conclusion

The comprehensive research revealed the level of corrosion resistance of the composite tubing liner. The results show that the composite tube liner made of steel 15H13N2MB when tested in a brine with a H\(_2\)S2650ppm concentration, pH = 2.6, for 720 hours showed a tendency to stress corrosion cracking at a load level of 60-80% of the actual yield strength in H2S saturated environment.

The average general corrosion rate during autoclave tests in a CO\(_2\) saturated environment was 0.22 mm/year under the condition of proportional steel merging, such corrosion rate data will provide 4 years of operation. In electrochemical studies the theoretical corrosion rate in a 5% NaCl brine was 0.59 mm/year.

Also, during autoclave and stress corrosion cracking tests, the pitting on the steel surface was found. It was shown that the tendency of chromium-nickel steels to pitting corrosion has a significant effect on the quality of its surface.

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