Methodology for studying the corrosion of material of oil pipelines operating in marshy soil

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Abstract. The main reason for the operation of oil pipelines is the corrosion of their materials. As a result of corrosion, the destruction of the pipeline, contributing to the leakage of oil, which pollutes the environment, accidents and disasters. The most corrosive areas are areas of high humidity, for example: swamps. In the Russian Federation, about 30 % of the transport network of oil pipelines passes through swampy soil. As the materials of oil pipelines, pipe steels are used, for example Steel of type 3 or 09Mn2Si. The article describes a method for studying the corrosion rate of pipe steels on a laboratory bench that simulates their operation in marshy soil. A comparison is made of the corrosion mechanisms of 09Mn2Si and Steel of type 3 steels in soils with a high content of hydrogen sulfide and the presence of microorganisms by empirical tests based on the above method. The results of gravimetric tests were evaluated and the conclusions were discussed.

1. Introduction

Currently, the largest part of all oil in Russian Federation is transported using oil pipelines, which are mainly laid underground, and therefore are subject to soil corrosion. In this case, soil corrosion of steel pipelines occurs according to the electrochemical mechanism, provoking the development of local types of corrosion processes - ulcer and pitting corrosion [1].

To protect against destruction of the pipe metal, mainly insulating coatings and electrochemical protection are used. However, due to the fact that the composition of the soil, its moisture and other parameters vary significantly along the route of oil pipelines in different areas, the rate of corrosion processes in these media will also be significantly differentiated. The pipelines passing through marshy soils undergo the most severe destruction, which has been noted by numerous studies and is easily confirmed theoretically [2,3].

The main reasons for the destruction of pipelines in marshy soils are [4]:

- high humidity and acidity of the medium;
- the presence of sulfur compounds;
- the presence of a large amount of carbon dioxide;
- exposure to various microorganisms.

Used to slow down the corrosion process in these areas of the reinforced type coating, due to the aggressiveness of the medium, they do not always give a satisfactory result. Due to the simultaneous exposure to acidic medium and microorganisms, coating uniformity is impaired. Moisture and cells of...
corrosive microorganisms get into the appeared defects in the coating; as a result, the pipeline metal in these areas intensely corrodes [5,6].

Corrosion destruction of the main pipelines in the sections of the soil – air transition represents a serious problem during its operation [6,7]. Often the reason for this phenomenon is the presence on the pipeline of coatings of dissimilar materials. The analysis of the literature data showed that the sections of the soil – air junctions are most often susceptible to pit and sunder film corrosion. Underground constructions made of carbon and low alloy steel, which are operated in aqueous chloride-containing media, are prone to ulcerative corrosion [8-12].

Pit corrosion proceeds in several successive stages:
1. the stage of nucleation;
2. stage of stable functioning of the corrosion centre;
3. the final stage.

If we consider the mechanism of this process, we can see that as a result of the lack of oxygen accelerated dissolution of the metal occurs, and as the damage deepens, the amount of oxygen decreases, respectively, the corrosion rate increases even more. In addition, as a result of diffusion of chlorine ions to the anode region of the metal, the corrosive medium at the dissolution site becomes more acidic, as a result of which the rate of metal destruction becomes even higher [13, 14]. Under the insulating coating is a solution of salts of various aggressiveness, causing ulcerative corrosion. The access of oxygen to the metal under the coating is much more difficult, and therefore, the conditions of differential aeration become even more stringent. Moisture falling under the coating causes delamination of the latter due to impaired adhesion, accumulates, and contributes to the development of corrosion by the electrochemical mechanism [15]. The coating ceases to be impermeable to moisture for various reasons: as a result of poor insulation, damage to the insulation layer after mechanical impact, if a medium enters the protected pipeline, to which the coating is unstable, etc. The situation is corrected by the phenomenon of repassivation of the local corrosion process, which occurs due to potential displacement during cathodic protection [16].

In order to protect the pipeline sections passing through marshy soil from destruction, it is necessary to apply comprehensive protective measures, which, however, are not always able to extend the life of the pipeline in these corrosive conditions. Therefore, in order to increase the service life of oil pipelines, it is recommended, in addition to the use of a reinforced type of protective coating and the installation of modern cathodic protection stations, to use steel in the construction and reconstruction of the pipeline as the pipe material, the most resistant in this medium [17].

In order to assess the corrosion resistance of pipe steel in a marshy soil medium, it is necessary to identify the significance of the main factors that pose the greatest danger to the pipeline metal. According to numerous studies [18,19], sulfur and its compounds, in particular hydrogen sulfide, which is often found in marshy soils, are one of the most dangerous corrosion factors. $\text{H}_2\text{S}$ poses a great danger to pipelines because of its ability to cause metal destruction even in small quantities, in particular, it often causes local corrosion, where it acts as a depolarizer. Hydrogen sulfide is also dangerous because of its ability to accelerate the diffusion of hydrogen into metal, causing hydrogen decay and stress corrosion cracking, which increase the brittleness of steel [20,21].

The presence of anaerobic and aerobic bacteria, which are an integral part of the fauna of swamps and are capable of stimulating the corrosion process by their vital functions, also plays a significant role in the destruction of metal in marshy soils [22,23]. Some bacteria are also able to directly or indirectly affect the technical condition of protective coatings, causing their premature destruction.

The increased humidity and acidity of the marshy soils accelerates the process of anodic dissolution of the metal, which, in combination with other factors of the marshy soils, can lead to the rapid emergence of local destruction of the pipeline, up to the formation of through damage [24].

2. Materials and methods

In order to determine the influence of external factors on the corrosion resistance of steels used in the construction of pipelines in the medium of marshy soil, an experiment of artificial destruction of metal
and a protective coating on a laboratory bench was proposed. For this, samples of Steel of type 3 and 09Mn2Si steels in the form of pipes and plates were placed in sealed containers in the amount of 4 pieces. In order to eliminate corrosion in the pipe space, pipe samples on both sides were insulated with sealant.

To simulate the operating conditions of pipes in marshy soil, which varies depending on the region of the country, four different media compositions were used. Black earth - 3 litres were placed in containers No. 1 and No. 2, sand of the same volume was placed in containers No. 3 and No. 4. In addition, water containing hydrogen sulfide and microorganisms was added to the tank. In containers No. 2 and No. 4 were added: 250 ml of water with hydrogen sulfide and 250 ml of water from a swamp containing anaerobic and aerobic microorganisms. In containers No. 1 and No. 3 were added: 450 ml of water with hydrogen sulfide and 50 ml of water from a swamp containing anaerobic and aerobic microorganisms (table 1).

Table 1. Composition of the medium in the capacities of the laboratory bench.

| Container No.1 | Container No.2 | Container No.3 | Container No.4 |
|----------------|----------------|----------------|----------------|
| Media          | Black earth    | Sand           | Sand           |
| Water containing hydrogen sulfide, ml | 450 | 250 | 450 | 250 |
| Water from a swamp, ml | 50 | 250 | 50 | 250 |

As can be seen from table 1, in all four containers the soil moisture was the same, and unchanged during the experiment, since the containers were sealed. The experiment was continued for two months, after which the state of the samples was evaluated visually and by gravimetric method. Gravimetric tests are to determine the change in mass of the samples during the test. The loss of mass of steel samples (mg) was calculated by the formula:

\[ \Delta m = m_0 - m_1 \]  

where \( m_0 \) – the mass of the sample before the test, mg; \( m_1 \) – the mass of the sample after the test, mg.

3. Experimental

As a result of the study, it was noted that the main destruction of the pipe samples occurred in the lower part, where the largest number of corrosion ulcers was observed. This arrangement of corrosion defects is associated with the phenomenon of differential aeration. Air oxygen unevenly enters the soil, which causes areas with different electrode potentials to appear on the surface of the sample. In this case, anode and cathode sections appear. At the anode sites, metal dissolves and a corrosive ulcer appears. Depolarization occurs at the cathode site, contributing to the development of the corrosion process. The results of gravimetric tests of samples of Steel of type 3 and 09Mn2Si steels are presented in Figure 1.

As can be seen from Figure 1, Steel of type 3 samples are less susceptible to destruction in a medium with a higher content of hydrogen sulfide. However, with an increased content of microorganisms in both sand and black earth, 09Mn2Si steel turned out to be more resistant to corrosion. Thus, tests have confirmed that wetlands are the most corrosive areas for the operation of oil mine pipelines. The use of standard methods of corrosion protection in such areas requires a special combined approach. It is necessary to take into account the effect of specific external factors on the development of pipe metal corrosion.

4. Conclusions

Studies have shown a high corrosion hazard in areas of marshy soils. The experimental comparisons of the corrosion resistance of 09Mn2Si and Steel of type 3 steels showed that Steel of type 3 has a higher
resistance in soil with a high content of hydrogen sulfide, but in the environment with a high content of microorganisms, 09Mn2Si steel showed better performance.

Figure 1. Weight loss of samples (mg).

Thus, it was found that for various sections of the pipeline that are in heterogeneous conditions, it is recommended to select the appropriate grade of pipe steel. For a full assessment of the corrosion state of the pipe metal in soil conditions, bench tests or pilot tests are required to identify the real rate of corrosion. Correct interpretation of the corrosion rate will allow the development of combined methods of corrosion protection with high efficiency. Reducing the corrosion rate of the main pipeline will prevent oil spills that pollute the environment, accidents and disasters.

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