Researching the operational properties of materials used in ECP

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Abstract. The goal of this research was to determine the corrosion resistance of metal materials used in ECP constructions as well as to determine the degree of degradation of the metal properties of rubber compounds (RS-3, TER-10, AF-15) after exposure to a corrosive environment. In order to assess the impact of a corrosive environment on changes in the mechanical properties of rubber compounds used in ECP constructions, tests were carried out for rubber samples of the compounds RS-3 (TU 2512-028-46521402-2014), TER-10 (TU 2512-028-46521402-2014), AF-15 (TU 2512-028-46521402-2014) in their initial state and after testing in a corrosive environment in an autoclave. Tests on samples of structural metal materials (05Cr16Ni4, 40Cr13, 40Cr, 22MnAl, Nirezist) in an aqueous saline solution containing ions of chlorides. According to these tests at 240, 480 and 720-hour exposure in the autoclave, the steel 05Cr16Ni4 is passive in the given corrosive environment and has a corrosion rate of \( \leq 0.01 \text{ mm/year} \). Tests of samples of four steels of grades 05Cr16Ni4, 40Cr13, 40Cr, 22MnAl in a solution of hydrochloric acid with pH = 0 over 6 hours at room temperature showed.

1. Introduction

Electric centrifugal pumps (ECP) are widely used in the oil industry as well as when developing mineral deposits by means of subterranean and above-ground methods [4, 5]. These pumps are operated in extreme well conditions: high temperatures and pressure, aggressive environment with a high concentration of chlorides, \( \text{H}_2\text{S}, \text{CO}_2 \), abrasive particles, excess gas - all of which leads to an intense deterioration of the working of the pump parts [1, 6]. New system standards of manufacturing processes, increased working temperatures, pressure, and rates lead to accelerated wear and tear of both individual parts and of the machines and mechanisms as a whole. Combined with the need to automate production, the problem of increasing the durability of the machines becomes even more urgent [9]. Selecting optimal materials for aggressive working conditions is relevant due to the importance of solving the problem. In order to ensure an optimal service life of the SRP, it is necessary to pay special attention to the choice of materials which meet requirements for corrosion, abrasion and cavitation resistance [3]. As a rule, standard materials for pump parts (such as cast iron, bronze and low-carbon steel) have the lowest cost and are the easiest to replace. However, as a result of their low corrosion resistance, premature equipment failure occurs, which significantly increases the final cost, taking into account service and replacements [2, 7]. The goal of this research was to determine the corrosion resistance of metal materials used in ECP constructions as well as to determine the degree of degradation of the metal properties of rubber compounds (RS-3, TER-10, AF-15) after exposure to a corrosive environment.
2. Materials and method of experiment

For the metal materials of an ECP construction, samples of steel 22MnAl, samples of steel 40Cr in a heated treated condition of 22-32 HRC, and samples of Nirezist cast iron were selected. The corrosion resistance of the selected materials was assessed using an autoclave. Testing for resistance to general corrosion was carried out on flat polished samples with a size of 50×30×4 mm.

In order to assess the impact of a corrosive environment on changes in the mechanical properties of rubber compounds used in ECP constructions, tests were carried out for rubber samples of the compounds RS-3 (TU 2512-028-46521402-2014), TER-10 (TU 2512-028-46521402-2014), AF-15 (TU 2512-028-46521402-2014) in their initial state and after testing in a corrosive environment in an autoclave. Tensile testing of the rubbers was conducted on a modified universal testing machine, model R5. The rubber samples were rectangular strips 150 mm long, 20 mm wide, and 2.5 mm thick. The length of an unclamped stretchable part of the sample measured 100 mm.

Two environments were chosen as the corrosive environment for testing:

0) an aqueous saline solution containing dissolved hydrogen sulfide and carbon dioxide: H₂S - 1.25 g/l; CO₂ - 1.15 g/l; Cl⁻ - 75 g/l; HCO₃⁻ - 1 g/l; Ca²⁺ - 9 g/l; (Na⁺+K⁺) - 40 g/l. Tests were carried out at a temperature of 120 °C, pH=3.0 and a pressure of 12 atm in the autoclave. Testing lasted for 720 hours;

1) hydrochloric acid with pH=0 at room temperature. Testing lasted for 6 hours [8].

In order to analyze changes to the rate of corrosion of the studied materials in time, experiments of various time bases were conducted. For this, four grades of steel were chosen: 05Cr16Ni4, 40Cr13, 22MnAl, 40Cr. The samples were removed from the autoclave after 240, 480 and 720 hours.

3. Research results and discussion

The conducted autoclave tests on metal materials for overall corrosion in an aqueous saline solution containing dissolved hydrogen sulfide and carbon dioxide and heated to a temperature of 120 °C show that the average rate of corrosion for Nirezist material equaled 0.47 mm/year and for steels of grade 22MnAl and 40Cr – 0.13 mm/year and 0.37 mm/year, respectively. Thus, it can be seen that the steel of grade 22MnAl has higher corrosion resistance in comparison to 40Cr grade steel and especially in comparison with Nirezist cast iron.

As a result of tests on samples of steel grades 05Cr16Ni4, 40Cr13, 22MnAl, 40Cr at various time bases, the rate of corrosion was calculated for materials with consideration of duration of contact with the test environment (Figures 1, 2).
The tested steels significantly differ from each other in the rate of corrosion: the lowest corrosion rate, not dependent on the duration of testing, is seen with stainless steel 05Cr16Ni4, whose corrosion rate does not exceed 0.01 mm/year. A slightly higher but still relatively low corrosion rate was seen with stainless steel with 13% chrome, which also decreases while in a corrosive environment, in comparison with steel 05Cr16Ni4. The corrosion resistance of low-alloy steels 40Cr and 22MnAl is slightly higher. The corrosion rate of these steels fluctuates between 0.03 mm/year and 0.10 mm/year. At the same time, increasing the time of exposure in a corrosive environment does not lead to a reduced corrosion rate of these steels. This is due to the fact that corrosion products forming on the surface of the samples poorly protect the metal, leading only to a noticeable scattering of the data obtained on corrosion rate. This explains the discrepancy in corrosion rate values for the indicated steels, which were obtained during preliminary and subsequent tests with 720 hours of exposure.

It should also be noted that when conducting corrosion testing of structural metal materials which show no formation of a thick protective film (carbon and low-alloy steel) on the surface of the samples when interacting with a solution, the forming corrosion products poorly protect the metal from dissolving. Therefore, in such cases, a large scattering of data on corrosion rates is observed. In order to divide these materials more precisely according to corrosion rates, it is advisable to increase the number of test samples.

Study results of steel samples in hydrochloric acid showed that the average value of corrosion for the steel of grade 05Cr16Ni4 equaled 0.21 mm/year, for 40Cr13 steels – 2.43 mm/year, 40Cr – 1.63 mm/year, 22MnAl – 4.12 mm/year. Thus, it can be seen that the most resistant to a hydrochloric acid environment with pH = 0 turned out to be 05Cr16Ni4 grade stainless steel. The surface of the samples of this steel remained shiny, with no visible traces of corrosion. Samples of the steel of grade 40Cr13 experienced general corrosion. Likewise, individual small holes (pitting) was observed on the surface. Due to the pitting corrosion, the steel of grade 40Cr13 displayed a slightly greater inclination to corrosion than the low-alloy steel of grade 40Cr. The corrosion rate of the steel of grade 22MnAl was at a maximum, which can be explained by the presence of manganese as an alloying element, which is more thermodynamically active than iron and other elements included in the composition of the steels.
Figure 3 presents a change in the appearance of the sample surface of steel 22MnAl when in a hydrochloric acid with pH = 0 (exposure time of samples – 45 minutes).

![Image of sample surface change](image)

**Figure 3.** Change in appearance of sample 22MnAl over 6 hours.

Research on the degradation of the metal properties of the samples of the rubber compound TER-10 is given in Figure 4.

![Diagram of tension of TER-10 samples](image)

**Figure 4.** Diagram of tension of TER-10 samples before (a) and after (b) exposure in an autoclave.
A diagram of the tension of RS-3 samples before and after exposure in an autoclave are given in Figure 5.

**Figure 5.** Diagram of tension of RS-3 samples before (a) and after (b) exposure in autoclave. The results of measuring the dependency of the load on the deformation for AF-15 samples before and after exposure in an autoclave are given in Figure 6.
Figure 6. Diagram of dependency on deformation for AF-15 samples before (a) and after (b) exposure in an autoclave.

Results of changes in the conditional tensile strength (GOST 270-75) and changes in the relative elongation during a rupture of samples of rubber compounds, grades RS-3, TER-10, AF-15, are given in Table 1.

Table 1. Mechanical properties of various grades of rubber compounds.

| Grade of rubber compound | Mechanical properties during tension | Degree of degradation, % |
|--------------------------|--------------------------------------|---------------------------|
|                          | Before testing                       | After testing             |
|                          | Force, N                              | Deformation, %            | Force, N | Deformation, % | In force | In deformation |


An analysis of the obtained results shows that in terms of both strength and deformation, the rubber compound of grade AF-15 is subject to the least degradation under the impact of a corrosive environment. The conditional strength was reduced 14.5%, while the relative elongation during rupture reduced 31%. For rubber compounds of grades RS-3 and TER-10, strength dropped 44% and 30%, respectively, while the plasticity (relative elongation) reduced 86% and 88%.

4. Conclusion
Based on the research conducted and analysis of the obtained data, the following conclusions can be made:

1. Tests on samples of structural metal materials (05Cr16Ni4, 40Cr13, 40Cr, 22MnAl, Nirezist) in an aqueous saline solution, containing ions of chlorides, bicarbonate, calcium, sodium, potassium, as well as dissolved hydrogen sulfide and carbon dioxide at a temperature of 120°C and autoclave pressure of ~1.2 MPa showed:

   1. After preliminary testing in the autoclave over 720 hours, all the studied materials (low-alloy steels of grade 22MnAl, 40Cr and Nirezist cast iron) displayed a tendency to general corrosion. The Nirezist cast iron has a maximum corrosion rate, which equaled around 0.47 mm/year. The corrosion rate of steels of grade 40Cr and 22MnAl was slightly lower than that of the cast iron, though noticeably different from each other (0.37 mm/year and 0.13 mm/year).

   2. According to these tests at 240, 480 and 720-hour exposure in the autoclave, the steel 05Cr16Ni4 is passive in the given corrosive environment and has a corrosion rate of ≤ 0.01 mm/year. Likewise, a rather low corrosion rate is seen with stainless steel with 13% chrome, which reduces over time in a corrosive environment. Steels 40Cr and 22MnAl have a corrosion rate of 0.059 to 0.075 mm/year after exposure in the test environment over 720 hours. A reduced corrosion rate was not discovered for the indicated steels when the testing period was increased, which is evidence of the low protective ability of the corrosion products formed on the surface of the samples. For the same reason, a noticeable scattering of the corrosion rate data for low-alloy steels is observed, which makes it impossible to rank them according to corrosion resistance.

2. Tests of samples of four steels of grades 05Cr16Ni4, 40Cr13, 40Cr and 22MnAl in a solution of hydrochloric acid with pH=0 over 6 hours at room temperature showed:

   2.1. The highest corrosion resistance was seen with the stainless steel of grade 05Cr16Ni4 with a corrosion rate of 0.21 mm/year.

   2.2. Steel of grade 40Cr13 experienced general corrosion in a solution of hydrochloric acid. Likewise, individual small holes (pitting) was observed on the surface. For this reason, the corrosion rate of 40Cr13 grade steel was slightly higher than that of the low-alloy steel of grade 40Cr (2.43 mm/year and 1.63 mm/year, respectively).

   2.3. The lowest resistance was seen with 22MnAl grade steel, which can be explained by the presence of manganese as an alloying element, which is more thermodynamically active than iron and other elements included in the steel’s make-up. The corrosion rate of the 22MnAl grade steel equaled 4.12 mm/year.

3. Autoclave testing of three grades of rubber compounds (RS-3, TER-10, AF-15) in a corrosive environment (pH = 3, temperature 120°C, duration of testing 720 hours) showed the following:

   3.1. In terms of both strength and deformation, the rubber compound of grade AF-15 was subject to the lowest degradation under the impact of a corrosive environment. The conditional strength reduced 14.5%, while the relative elongation during rupture reduced 31%.

   3.2. For rubber compounds of grades RS-3 and TER-10, the strength dropped 44% and 30%, respectively, while the plasticity (relative elongation) reduced 86% and 88%, respectively.

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