RESEARCH OF OPERATIONAL PROPERTIES OF MATERIALS APPLIED IN IECP

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ABSTRACT

The main spectrum of materials used in ESP designs is considered. The corrosion resistance of metallic materials, as well as the degree of degradation of the mechanical properties of rubber compounds after exposure in a corrosive environment, simulating operational effects, have been determined. Autoclave tests of structural metallic and nonmetallic materials were carried out in an aqueous-salt solution containing chloride, bicarbonate, calcium, sodium and potassium ions, as well as dissolved hydrogen sulfide and carbon dioxide at a temperature of 120 °C. Also metal tests in the field of hydrochloric acid with a pH value equal to zero. Corrosion rates are calculated to take into account the duration of contact with the test medium. The effect of a corrosive environment on the change in the mechanical properties of rubber compounds has been investigated. This article opens a series of studies to establish relationships in the "composition-structure-properties" triad for ESP materials under various operating conditions.

KEYWORDS: IECP, Autoclave Test, Corrosion Resistance, Degradation of Rubber Compounds, Mechanical Properties & Oil and Gas Industry

INTRODUCTION

In the oil industry and in the development of mineral deposits by underground and open-pit methods, installations of electric centrifugal pumps (IECP) are widely used [7, 8]. Pumping units are operated under special conditions in the well: high temperatures and pressures, aggressive environment with a high content of chlorides, H₂S, CO₂, the presence of abrasive particles, excess gas - all this leads to intensive wear of the working parts of the pumps [1, 9]. Operation of materials of oil equipment in aggressive media, such as chlorine ions (Cl⁻), carbon dioxide (CO2) and hydrogen sulfide (H2S), seriously threatens the safety and reliability of these systems, entails the problem of premature equipment failure [4, 5, 10, 16, 18, 19]. New standards of production process systems, an increase in operating temperatures, pressures and speeds, leads to accelerated wear of both individual parts and machines and mechanisms as a whole, and in combination with the need to production automation, makes the problem of increasing the durability of machines even more acute [14]. The relevance of the selection of optimal materials for aggressive operating conditions is due to the importance of solving the problem. To ensure optimum service life of the ECP, it is necessary to pay special attention to the choice of materials that meet the requirements for corrosion, abrasion and cavitation resistance [6] Standard materials for pump parts (such as cast iron, bronze and mild steel) tend to be the lowest cost and most readily available for replacement, however, as a result of their low corrosion
resistance, premature equipment failure occurs, which significantly increases the total cost, taking into account service and replacement [2, 12]. In the presence of an aggressive environment, it is advisable to use special alloyed grades of cast iron, nickel-resist, corrosion-resistant and duplex steels, etc. To select the optimal material for the operation of certain parts of the ESP requires a detailed understanding of the processes occurring in the critical parts of the ESP during operation [3, 11, 15, 17]. The purpose of this study is to familiarize with the range of materials used in ESP structures, to determine the corrosion resistance of metallic materials, and to determine the degree of degradation of the mechanical properties of rubber compounds (RS-3, TEP-10, AF-15) after exposure to an aggressive environment. This article opens a series of studies to establish relationships in the composition-structure-properties triad for ESP materials under various operating conditions.

MATERIALS AND METHODS OF THE EXPERIMENT

Samples of steel brand 22MnAl, samples of steel brand 40Cr in a heat-treated state of 22 - 32 HRC, and samples of cast iron of the Ni-Resist type 1 were selected as metal materials for the ECP structure. The corrosion resistance of the selected materials was evaluated using an autoclave. Tests for resistance to general corrosion were carried out on flat polished samples with dimensions of 50 × 30 × 4 mm.

To assess the effect of a corrosive environment on the change in the mechanical properties of rubber mixture brands used in ECP construction, tests were carried out for samples of rubber mixture brands RS-3 (TU 2512-028-46521402-2014), TER-10 (TU 2512-028-46521402-2014), AF-15 (TU 2512-028-46521402-2014) in the initial state and after tests in a corrosive environment in an autoclave. Tensile tests of rubber mixture brands were carried out on a modified model P5 tensile testing machine. Rubber samples were rectangular strips 150 mm long, 20 mm wide, 2.5 mm thick. The length of the unclamped stretched part of the sample was 100 mm.

Two environments were selected as corrosive test media:

- 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. The tests were carried out at a temperature of 120 °C, pH = 3.0 and an autoclave pressure of 12 atm. The duration of the test was 720 hours;

- hydrochloric acid with pH = 0 at room temperature, test duration was 6 hours [13].

To analyze changes in the corrosion rate of test materials over time, experiments were conducted on different time bases. For this, 4 steel brands were selected: 05Cr16Ni4, 40Cr13, 22MnAl, 40Cr the samples were removed from the autoclave after 240, 480 and 720 hours.

RESEARCH RESULTS AND THEIR DISCUSSIONS

Autoclave tests of metal materials for general corrosion in a water-salt solution containing dissolved hydrogen sulfide and carbon dioxide and heated to a temperature of 120 °C showed that the average corrosion rate of NiResist material is 0.47 mm/year, steels of brands 22MnAl and 40Cr - 0.13 mm/year and 0.37 mm/year, respectively.
The investigated steels differ significantly from each other in the magnitude of the corrosion rate: the lowest corrosion rate, regardless of the test duration, is possessed by 05Cr15Ni4 stainless steel, the corrosion rate of which does not exceed 0.01 mm / year. Stainless steel with 13% chromium has a slightly higher, but also rather low corrosion rate, which, moreover, decreases with the time spent in a corrosive environment, in comparison with steel 05Cr15Ni4. The corrosion resistance of low-alloy steels 40Cr and 22MnAl is slightly higher, the corrosion rate of these steels ranges from 0.03 mm/year to 0.10 mm/year. Moreover, an increase in the exposure time in a corrosive environment does not lead to a decrease in the corrosion rate of these steels. This is due to the fact that the corrosion products formed on the surface of the samples weakly protect the metal, only leading to a noticeable scatter of the obtained data on the corrosion rate. This also explains the discrepancy in the values of the corrosion rate of these steels, which were obtained during preliminary and
subsequent tests with a holding time of 720 hours.

It should also be noted that during corrosion tests of structural metal materials, in which a dense protective membrane does not form on the surface of the samples when interacting with the solution (carbon and low-alloy steels), the resulting corrosion products weakly protect the metal from dissolution. Therefore, in such cases, there is a large scatter of data on the corrosion rate and for a more accurate separation of such materials by corrosion resistance, it is advisable to increase the number of test samples.

The results of testing steel samples in hydrochloric acid showed that the average value of corrosion for steel brand 05Cr15Ni4 is 0.21 mm/year, for steel brands 40Cr13 - 2.43 mm/year, 40Cr - 1.63 mm/year, 22MnAl - 4.12 mm/year. Thus, it can be seen that the most resistant to hydrochloric acid at pH = 0 turned out to be stainless steel of brand 05Cr15Ni4. The surface of the samples made of this steel remained shiny, without visible signs of corrosion. Samples of steel brand 40Cr13 underwent general corrosion. Separate small pittings were also observed on the surface. Due to pitting corrosion, steel brand 40Cr13 showed a slightly greater tendency to corrosion than low-alloy steel brand 40X. The corrosion rate of steel brand 22MnAl was maximum, which can be explained by the presence of manganese as an alloying element, which is more thermodynamically active than iron and other elements that make up the steels.

Figure 3 shows the change in the appearance of the surface of a 22MnAl steel sample when it is in hydrochloric acid with pH = 0 (the exposure period of the samples is 45 minutes).

![Figure 3: Change in the Appearance of the 22MnAl Sample within 6 Hours.](image)

The study of the degradation of the mechanical properties of the TER-10 rubber mixture samples is shown in figure 4.
The tensile diagram for RS-3 samples before and after holding in an autoclave is shown in figure 5.
The results of the change in the conventional tensile strength (GOST 270-75) and the change in the relative elongation at rupture of samples of rubber mixtures of the RS-3, TER-10, AF-15 brands are shown in table 1.

<table>
<thead>
<tr>
<th>Rubber Mixture Brand</th>
<th>Tensile Mechanical Properties</th>
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<tr>
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<td>Before Testing</td>
<td>After Testing</td>
<td></td>
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<td></td>
<td>Effort, N</td>
<td>Deformation, %</td>
<td>Effort, N</td>
<td>Deformation, %</td>
<td>Degradation Rate, %</td>
<td>By Effort</td>
</tr>
<tr>
<td>RS-3</td>
<td>337</td>
<td>128</td>
<td>190</td>
<td>18</td>
<td>44</td>
<td>86</td>
</tr>
<tr>
<td>TER-10</td>
<td>815</td>
<td>237</td>
<td>570</td>
<td>28</td>
<td>30</td>
<td>88</td>
</tr>
<tr>
<td>AF-15</td>
<td>427</td>
<td>215</td>
<td>365</td>
<td>148</td>
<td>14,5</td>
<td>31</td>
</tr>
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</table>

The analysis of the data obtained shows that both in terms of strength and deformation characteristics, the rubber mixture of the AF-15 brand is subject to the least degradation under the influence of a corrosive environment. The
reduction in the relative strength was 14.5%, and the reduction in the elongation at break was 31%. For rubber mixture brands of the RS-3 and TER-10 brands, the drop in strength was 44% and 30%, respectively, and the decrease in plasticity (relative elongation) was 86% and 88%.

CONCLUSIONS

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

- Tests of samples of structural metal materials (05Cr15Ni4, 40Cr13, 40Cr, 22MnAl, NiResist Type1) in an aqueous saline solution containing ions of chlorides, bicarbonate, calcium, sodium and potassium, as well as dissolved hydrogen sulfide and carbon dioxide at a temperature of 120 °C and an autoclave pressure ~ 1.2 MPa showed:
  - After preliminary tests in an autoclave for 720 hours, all investigated materials (low-alloy steels of 22MnAl, 40Cr brands and cast iron of the NiResist type) showed a tendency to general corrosion. Cast iron of the NiResist type has a maximum corrosion rate of about 0.47 mm/year. The corrosion rates of steels of brand 40Cr and brand 22MnAl are somewhat lower than those of cast iron, but they differ markedly among themselves (0.37 mm/year and 0.13 mm/year respectively).
  - According to the test data at 240, 480 and 720-hour exposure in an autoclave, 05Cr15Ni4 steel is passive in this corrosive environment, and has a corrosion rate of ≤ 0.01 mm/g. Also, stainless steel with 13% chromium has a fairly low corrosion rate, which decreases with time in a corrosive environment. Steel brands 40Cr and 22MnAl have corrosion rates of 0.059 to 0.075 mm/year after exposure in the test environment for 720 hours. For these steel brands, no decrease in the corrosion rate was found with an increase in the test duration, which indicates a low protective ability of the corrosion products formed on the surface of the samples. For the same reason, there is a noticeable scatter of data on the corrosion rate of low-alloy steels, which does not allow ranking them by corrosion resistance.

- 2. Testing samples of 4 brands of steel (05Cr15Ni4, 40Cr13, 40Cr and 22MnAl) in hydrochloric acid solution at pH = 0 for 6 hours at room temperature showed:
  - 2.1. Stainless steel brand 05Cr15Ni4 has the highest corrosion resistance: its corrosion rate is 0.21 mm/year.
  - 2.2. Steel brand 40Cr13 undergoes general corrosion in a hydrochloric acid solution, and some small pittings were also observed on the surface. For this reason, in terms of the corrosion rate, steel brand 40Cr13 was slightly higher than that of low-alloy steel brand 40Cr (2.43 mm/year and 1.63 mm/year, respectively).
  - 2.3. Steel brand 22MnAl has the lowest resistance, which can be explained by the presence of manganese as an alloying element, which is more thermodynamically active than iron and other elements that make up the steels. The corrosion rate of 22MnAl steel is 4.12 mm/year.

- 3. Autoclave tests in a corrosive environment (pH = 3, temperature 120 °C, test duration 720 hours) of rubber mixtures of three brands (RS-3, TER-10, AF-15) showed the following:
  - 3.1. Both in terms of strength and deformation characteristics, the AF-15 rubber mixture brand is subject to the least degradation under the influence of a corrosive environment. The reduction in the relative strength was
14.5%, and the reduction in the elongation at break was 31%.

3.2. For rubber mixtures of the RS-3 and TER-10 brands, the drop in strength was 44% and 30%, respectively, and the decrease in plasticity (relative elongation) was 86% and 88%, respectively.

4. Within the framework of the study the corrosion mechanism was not studied, this problem is subject to detailed consideration and will be the subject of study in subsequent articles devoted to the study of the composition-structure-property relationships for ESP materials under various operating conditions.

REFERENCES

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