Development of innovative methods of increasing the service life of equipment and pipelines

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Abstract. Knowing the specific technological parameters of water source and piping systems, it is possible to determine the service life of the pipe set, as water source as pipelines, by the offered method. Complex-acting, multifunctional, thermally resistant, bactericidal type new corrosion inhibitor based on naphthenates has been developed; The technology of insulation of the surface of metal pipes with coatings made of non-corrosive, shock-resistant and corrosion-resistant basalt-plastic and glass-plastic materials has been developed. Possibility of application of basalt-plastic and glass-plastic materials in construction and repair of tanks and other capacities was studied; Technologies for the production of protective belts, transport pipes, as well as rods from pure basalt-plastic and fiberglass materials in the highly corrosive environment were developed and their application together with metal pipes and rods was analyzed.

Knowing the specific technological parameters of water source and piping systems, it is possible to determine the service life of the pipe set, as water source as pipelines, by the new method. During the research, the physicochemical factors affecting the object were investigated and methods of elimination were developed: Innovative methods of corrosion protection to increase the service life of equipment and transport pipelines, as well as a statistical method to determine the dependence of the capacity of equipment and transport pipelines on mechanical, physical and chemical factors; complex-acting, multifunctional, thermally resistant, bactericidal type new corrosion inhibitor based on naphthenates has been developed.

1. Introduction
When steel samples are immersed in a neutral salt solution, their surface corrodes. If the surface of these specimens is periodically scrubbed, the corrosion rate becomes more intense than on the untreated surface. Here the oxidized surface plays a protective role. Experiments show that the regularly cleaned surface of the steel metal, under the influence of a neutral salt solution, directs the potential of the steel in a negative direction of a few millivolts. Thus, there is a potential difference between the untreated surface of the sample and the cleaned surface [1, 2]. As the friction on the metal surface deepens, the potential difference between the oxide layer, which plays a protective role, increases. Without friction between the pump compressor tubes and the rods, the metal surface is cleaned of the oxide layer, and a macro pair is formed between the untreated surface and the cleaned surface. The cleaned part acts as an anode function. In addition, mechanical impurities in the system (quartz sand) are involved in the corrosion (scraping or scraping) of the oxide layer in the metal.

Thus, the processes of corrosion and corrosion-erosion in equipment systems and transport pipelines are multifactorial. This problem is solved in the classical method by changing one parameter...
and keeping the remaining parameters constant. However, such an approach to the issue takes a long time. Thus, each factor requires its own set of experiments [3-6]. This is not used in studying the effects of other factors. For example, the intensity of corrosion and mechanical-corrosion erosion of equipment and transport pipelines depends on various factors: the rate of corrosion of steel, the influence of aggressive formation waters, surface tension, fluid flow rate, service life, the impact of aggressive gases, etc. depends. The effects of each of these factors have been studied separately. However, no research has been conducted to study the combined effects of these factors.

2. Methods and materials
To solve the problem, a mathematical statistical method was proposed by obtaining simple analytical expressions that connect various mechanical and physicochemical factors with the main indicators of the process. A mathematical model of corrosion and mechanical corrosion is developed using the group accounting method of arguments [7-9]. This method differs from other mathematical methods by its high level of correlation and low initial values. Provides a record of the impact of various factors during the process and identifies the factor that affects them the most. In general, the function of the process is as follows:

\[ y = a_1 \cdot f_1(x_1, x_2, ..., x_n) + a_2 \cdot f_2(x_1, x_2, ..., x_n) + \ldots + a_m \cdot f_m(x_1, x_2, ..., x_n) \] (1)

The solution of the problem of determining the dependence of the performance of pump-compressor pipes on the influence of mechanical and physicochemical factors was carried out in 2 stages. In the first stage, the process of corrosion of steel pipes in the water-source environment was studied, and in the second stage, the service life of pump-compressor pipes was studied. In order to obtain a physical model of the corrosion process of steel in the form of corrosion in the water source system, 2 massive initial indicators of sodium hydrocarbonate - "alkali" and calcium chloride – ‘hard’ type produced waters typical for watersource fields of Azerbaijan were given [4, 6]. In both cases, the variable and total experimental values are n = 11 and N = 50. The actual corrosion rate in the flow of 45 grade steel metal water-source system was determined on a laboratory device. The velocity of the liquid in the discharge channel is determined by the following formula:

\[ V = 0.032 \cdot \mu \cdot \sqrt{2gh} \] (2)

Here, V - the flow rate of the liquid, in m/s; \( H \) - water manometer reading, in mm; \( \mu \) - 0.82 - coefficient of hydraulic resistance; \( g \) - 9.81 m/sec release emergency.

According to Kulbak's formula, the awareness of the indicators included in the array was estimated

\[ j(x_i^j) = D \cdot k(x_i^j) \cdot \frac{1}{2} \left[ p \left( \frac{x_i^j}{A} \right) - p \left( \frac{x_i^j}{B} \right) \right] \] (3)

where, \( D \cdot k(x_i^j) \) i in the range \( j \) - diagnostic coefficient in the sign;
\( p \left( \frac{x_i^j}{A} \right) \) - j probability to fall into group A in the sign;
\( p \left( \frac{x_i^j}{B} \right) \) - j probability to fall into group B in the sign.

Calculations show that the characters included in the array are arranged in the following order according to the information: fluid flow rate \( j = 3.20 \); the amount of H2S \( j = 1.65 \); amount of water \( j = 1.02 \); water stability \( j = 0.78 \); amount of chlorides \( j = 0.67 \); pH (environment) \( j = 0.63 \); minerality \( j = 0.53 \); water activity \( j = 0.48 \); temperature \( j = 0.40 \); amount of bicarbonates \( j = 0.21 \).

After processing the experimental parameters, a physical model of the corrosion process in steel was obtained:

\[ y_1 = 0.06441 \cdot \frac{x_9}{x_6 \cdot x_7} \cdot \frac{1.564}{\sqrt{x_{12}}} - 0.1402 \cdot \frac{\sqrt{x_7}}{x_{10}} - 0.2611 \cdot \frac{\sqrt{x_{10}}}{x_2} + \frac{0.0343}{x_6} \cdot \frac{\sqrt{x_3 \cdot x_8}}{x_6} - 1.142 \cdot \frac{\sqrt{x_5 \cdot x_{12}}}{x_6} \] (4)
- in the oil and gas system containing calcium chloride formation water:

$$y_2 = 0.1312 \cdot x_9 \cdot x_{12} \cdot \sqrt{x_7} + 2.6001 \cdot x_9 \cdot \sqrt{x_6} - 50.9 \cdot \frac{\sqrt{x_5}}{\sqrt{x_7 \cdot x_8}} + 0.8255 \cdot \frac{1}{\sqrt{x_{10}}} - 2.968 \cdot \frac{x_9 \sqrt{x_7}}{x_7 \cdot x_{12}} - 0.01705 \cdot x_{11} \cdot \sqrt{1 \cdot x_4 \cdot x_5}$$

(5)

Here: $y_1$ - corrosion rate of 45 grade steel in dissolved gases (H$_2$S, O$_2$ and CO$_2$), g / m$^2$ · h; $y_2$ - corrosion rate of 45 grade steel in dissolved gases (H$_2$S, O$_2$ and CO$_2$) and containing "cod" type formation water, g / m$^2$ · h;

$x_1$ - total mineral content of produced water, kg / m$^3$;

$x_2$ - amount of sodium and potassium chloride in water kg / m$^3$;

$x_3$ - fluid flow rate, m / sec;

$x_4$ - amount of calcium and magnesium chlorides in water, kg / m$^3$;

$x_5$ - amount of calcium and magnesium hydrocarbons in water, kg / m$^3$;

$x_6$ - pH environment;

$x_7$ - amount of hydrogen sulfide in water, g / m$^3$;

$x_8$ - ambient temperature, °C;

$x_9$ - fluid flow rate, m / s;

$x_{10}$ - amount of water in the system, %;

$x_{11}$ - coefficient taking into account the percentage of organic acids, wetting the metal surface, in water;

$x_{12}$ - coefficient of water stability - pH of pH environment.

$$J = \frac{p}{p_{\text{sat}}}$$

$p_{\text{sat}}$ corresponds to the equilibrium state of the solvent and is determined by the following formula:

$$\text{pH}_{\text{doy.}} = pK_2 - pS_{\text{CaCO}_3} - \lg[Ca^{2+}] - \lg[Q_{\text{total}}] + 2.5\mu + 7.6.$$  

(6)

Here, $p$ is the total amount of salts in water in g / m$^3$; $K_2$ is thermodynamically stable; $S_{\text{CaCO}_3}$ is a solution; $Ca^{2+}$ is the concentration of calcium ion in g / m$^3$; $Q_{\text{total}}$ is the total alkalinity of water - wiz q - ekv/m$^3$; $\mu$ is the ionic strength of the solvent.

The obtained dependence shows a high correlation of 0.872 and 0.932, respectively.

The absolute errors of the calculated values of the corrosion rate in relation to the actual values in practice are as follows:

- $\Delta y_1 = \pm 0.3$ g / m$^2$ · hour (average square error 6.4%) for produced water of sodium bicarbonate type;

- for calcium chloride type formation water $\Delta y_2 = \pm 0.185$q/m$^2$ · h (average square error 3.5%).

3. Results and discussion

With the help of the obtained model, sodium bicarbonate type water ("alkaline" type), calcium chloride type ("cod" type) produced water and low-active water and gas system containing up to 500 g / l H$_2$S, 25 to 100 Under the specific operating conditions of the equipment operated in the range of °C, the liquid flow is from 0.1 to 1.0 m / sec. The corrosion rate of 45 grades of steel was calculated at the rate of 50 to 98% of the irrigation. The corrosion rate of the medium containing sodium hydrocarbonate ("alkaline" type), the minerality and pH of which are as follows, is calculated for 4 cases:

- 50mg - eq / 100g and pH = 8.0 - 8.5; 100 mg-equ / 100g and pH = 7.5 - 8.0; 150 mg-equ / 100g and pH = 7.0 - 7.5; 200 mg - eq / 100g and pH = 6.5 - 7.0; (Appendix 1 - 4).

The corrosion rate for a medium containing calcium chloride (‘hard’ type) aquifers with mineral content and pH is calculated for 4 cases: 250 mg-equ / 100g and pH = 6.2 - 6.7; 350 mg-equ / 100g and
pH = 5.9 - 6.4; - 450 mg-eq / 100g and pH = 5.6 - 6.1; 550 mg-eq / 100g and pH = 5.3–5.8 (Appendix 5–8).

With the help of these tables, it is possible to accurately determine the rate of corrosion erosion in equipment by knowing some information about the physical and chemical composition, properties, irrigation ratio and temperature in the absence of mechanical wear and friction. The rate of corrosion of the bottom of reservoirs for various purposes is influenced by the environment - the mineralization of oil-bearing water. The curves based on the correlation rate between the corrosion rate of the bottom of the reservoir and the mineral content of the water separated from the oil (the values of these indicators correspond to the values of the statistical indicators) are shown in Figure 1.

![Fig. 1. Curves of the mineral content of produced water showing the corrosion rate (K) of the bottom of reservoirs containing (S) commercial (1), technological (2) and crude oil (3).](image)

The dependence of the corrosion resistance of low-alloy steels on some factors is shown in Table 1.

| Minerality q/l | Alkalinity mmol/l | Test conditions | Corrosion rate mm/year |
|----------------|-------------------|----------------|-----------------------|
| 20             | 2.2               | t = 20°C       | 0.0                   |
| 200            | 1.8               |                | 0.03                  |
| 20             | 136.0             |                | 0.07                  |
| 200            | 1.8               | t = 40°C       | 0.13                  |
| 20             | 136.0             |                | 0.11                  |
| 200            | 2.2               | t = 20°C       | 0.18                  |
| 20             | 2.2               | t = 20°C       | 0.14                  |
| 200            | 1.8               |                | 0.05                  |
| 20             | 136.0             |                | 0.13                  |

As a result, the following dependence was obtained after processing the indicators:

$$Z_1 = 229.1 \cdot \frac{x_{13}}{\sqrt{x_{15} \cdot x_{16} \cdot x_{18}}} + 0.2924 \cdot \frac{x_{14}}{x_{17} \cdot \sqrt{x_{15} \cdot x_{18}}} + 53.48 \cdot \frac{x_{13}}{\sqrt[3]{x_{14}}} - 1285 \cdot \frac{x_{13} \cdot x_{18}}{x_{14}}$$  \hspace{1cm} (7)

$$Z_2 = 0.03365 \cdot \frac{x_{13}^2}{\sqrt{x_{16} \cdot x_{18}}} + 7.234 \cdot \frac{x_{13}^2}{x_{17} \cdot \sqrt{x_{15} \cdot x_{17}}} - 0.7689 \cdot x_{13}^2 \cdot x_{16} \cdot \sqrt{x_{17} \cdot x_{18}}$$  \hspace{1cm} (8)

Here: $z_1$ and $z_2$ - service life of the pipe set made of branded steel, expressed in days, in the process of new construction;

$Y$ - g / m² - is the corrosion rate of 45 grades of steel, expressed in pump-compressor pipes, 45 grades of steel, installed on the discharge line and stored for 18 ... 20 days;

The calculation by the Kulbak formula shows the curvature $J = 2.84$; corrosion rate - 0.67;
\( x_{13} \) - pipe wall thickness, in mm;
\( x_{14} \) - is the coefficient characterizing the gap between the pump compressor pipe and the rod belt, which determines the relationship between the diameter of the pipe and the diameter of the belt;
\( x_{15} \) - \( \text{m/ min} \), which characterizes the total length of the deep-pump rod set that can pass through the pump-compressor pipes. is a parameter expressed by;
\( x_{16} \) - pump suspension depth, in m;
\( x_{17} \) - amount of mechanical mixture (quartz sand) in the product in kg / m³;
\( x_{18} \) - coefficient expressed in rad./m, which characterizes the ratio;
\[
x_{18} = \frac{\Delta}{l}
\]
Here: \( \Delta \) - \( l \) cross-sectional curvature of the water source trunk, rad. \( l \) - section length, in m.
The size of \( D \) should be determined taking into account the curvature and azimuth of the body. For pipes is determined by the following formula:
\[
\Delta = \sqrt{\delta_1^2 + \delta_2^2 - 2\delta_1 \cdot \delta_2 \cdot \cos \Delta \cdot \beta}
\]
Here, \( \delta_1 \) - \( l \) - the curvature of the water source trunk at the beginning of the interval, \( \text{rad} \); \( \delta_2 \) - \( l \) - curvature of the water source trunk at the end of the interval, \( \text{rad} \); \( \Delta \cdot \beta \) - difference in azimuths at the beginning and end of the interval, \( \text{rad} \). \( \Delta \) \( \neq \) \( \beta \) - an inclinogram of the water source (special scale).

Analysis of formulas (7) and (8) shows that the performance of pump-compressor pipes is mainly related to:
- occurrence of mechanical wear due to vibrations between the pump compressor pipes and the depth pump rods; where the curvature of the water source trunk and the dynamic load (tension) in motion are taken into account.
- figurative erosion, depending on the gap between the pipes and the rods, the amount of mechanical impurities (quartz sand) in the water source product;
- corrosion of pipes under stress (under pressure).

Knowing the specific technological parameters of water source and piping systems, it is possible to determine the service life of the pipe set, as water source as pipelines, by the above method. The performance of equipment and transport pipelines in water source-assembly systems depends on the corrosion and corrosion-erosion effects of the produced water source products, the erosion of the surfaces in contact with the vibrations, and many other factors. The informative evaluation of these symptoms by the Kulbak method shows that:
- Spillage of steel metal in the water and gas system as a result of KP depends on the flow rate of the liquid, the amount of hydrogen sulfide, carbon and oxygen gas in the watersource product, minerals (mainly chlorides, hydrocarbons and carbonates), ambient temperature, pH, surface activity, formation water stability, coefficient and so on. depends.
- The performance of the equipment in the conditions of mechanical-corrosion wear depends on the curvature of the water source trunk, the rate of corrosion of the equipment material in the watersource product flow, the suspension depth of the lift pipes, the wall thickness, the gap between the pump compressor tubes and the rod belt, fluid removal rate and amount of mechanical impurities.

4. Summary
During the research, the physicochemical factors affecting the object were investigated and methods of elimination were developed: Innovative methods of corrosion protection to increase the service life of equipment and transport pipelines, as well as a statistical method to determine the dependence of the capacity of equipment and transport pipelines on mechanical, physical and chemical factors. Complex-acting, multifunctional, thermally resistant, bactericidal type new corrosion inhibitor based on naphthenates has been developed; The technology of insulation of the surface of metal pipes with coatings made of non-corrosive, shock-resistant and corrosion-resistant basalt-plastic and glass-plastic
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