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MATHEMATICAL MODELING OF LOCAL CORROSION ELEMENT IN PIPELINES WITH GALVANIC COUPLE OPERATING IN SOIL CONDITIONS

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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ЛОКАЛЬНОГО КОРОЗІЙНОГО ЕЛЕМЕНТА НА ТРУБОПРОВОДІ ПРИ РОБОТІ ГАЛЬВАНОПАРИ В ГРУНТОВИХ УМОВАХ

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ЛОКАЛЬНОГО КОРРОЗИОННОГО ЭЛЕМЕНТА НА ТРУБОПРОВОДЕ ПРИ РАБОТЕ ГАЛЬВАНОПАРЫ В ГРУНТОВЫХ УСЛОВИЯХ

Abstract. Solution of the problem of modeling electrochemical corrosion in the pipeline sector with cracked insulating coating under the effect of electrolytic medium aggressive towards the pipeline metal is presented in this paper. The problem boils down to determining a stationary electrolytic field which occurs in the pipeline sector (a) in the crack when galvanic macrocouple operates with anode and (b) under the pipeline insulating coating when galvanic macrocouple operates with cathode. The advantage of this model is its ability to predict corrosion of the pipeline on time, which is important for determining the residual life of the structure. Distribution of potential electric field is determined by solving of the Laplace two-dimensional differential equation with given boundary conditions hence helping to obtain functional dependencies for calculation of current density (corrosion rate) and operating electric the acting galvanic macrocouple "crack in the metal - metal under the insulation coating"

Keywords: electrochemical corrosion, underground pipelines, corrosion current.

The problem of reliability and environmental safety of main gas, oil-and-gas, utility pipelines is gaining particularly acuteness.

Lifetime of main gas and oil pipelines of Ukraine, in many cases is close to the planed values. Numerous corrosive damages to the pipes' external surfaces are revealed, thus exacerbating the problem of the pipes' further reliable and safe operation.

The available publications analysis [1-6] showed that forecasting the residual life of pipelines is a multifactor task lying in determining their operating capacity ultimate permissible state. At present, there are no criteria to specify the main pipelines elements' ultimate permissible state for pipelines which have been in operation for over 200 thousand hours, as well as the methods of forecasting the residual resource with the proper reliability [2].

The existing regulatory support of safe pipelines operation does not fully regulate the comprehensive analysis of pipelines to determine their residual life, as it does not take into account the specifications and parameters that have changed during their operation life under the influence of operational factors, including corrosive wear [7].

Studying conditions of pipelines operation under the influence of soil corrosion shows that despite the use of different measures, the number of accidents due to corrosion of pipelines in the industry makes 27% of their total number.

Virtually, any insulation coating does not provide complete protection of the underground pipeline, due to defects in the cover itself, causing the electrochemical contact set between the electrolyte and the pipe. Once the fact of the cover damage has been established, the problem arises of forecasting the time of leakage due to corrosion of pipes.

Particularly acute the above issue is concerning pipelines operated in the sites where the pipe insulation is broken due to electrolytic solutions getting into the pipes. Such sites are significantly influencing the development of the pipeline's corrosion, creating conditions for the emergence of macro-corrosion couples. In underground pipelines with the broken insulation sites, anode and cathode polarization characteristics of steel are significantly changing and, consequently, the potentials of steel in these places are changing, too.

Considering that the exploitation of oil pipeline with the areas where insulation is broken is connected with the pipeline's electrochemical corrosion, an increased focus of environmental safety operation of the pipeline should be put on the pipeline's corrosion losses definition in the insulation damage areas as a result of the corrosion element's effect. Solving the problems of early pipeline corrosion detection, determine its rate and creepage will prevent accidents at the oil pipeline and provide its environmental safety.

Insulation cover, as a porous material, is a second-class conductor, so the process of reinforcement corrosion in it may be regarded as a conventional electrochemical corrosion of metals in electrolytes. In most cases, including the corrosion of steel pipe in the insulation crack place, heterogeneous mechanism of metal destruction is dominating, when separate parts of the metal surface are the cathodes (a tube segment under a layer of insulating coating), and the others being anodes (pipes in the crack area).

This mechanism of corrosion rate is determined by a number of parameters that characterize the electrochemical heterogeneityof the system: potentials and polarization of anode and cathode segments, the specific electrical conductivity system, the geometric dimensions of land areas.

In this formulation, the problem of electrochemical corrosion in steel pipe under the coating is reduced to determining static electric field that occurs when galvanic macro-couple is operating with heterogeneous electrode, i.e. to writing equations and boundary conditions formulas to be answered by this field's potential.

One of the main parameters that characterize corrosion processes on the metal pipe surface is the current density. In the pipeline areas where insulation is damaged conditions arise for emergence of macro-corrosion couples, the current load of which can be used as a general characteristic at determining the losses on the pipeline's metal.

The electric field near the heterogeneous electrode has been considered, which model consists of 2 random width sites different in their stationary potentials.

Local corrosion element is represented by a segment of the pipeline under the insulation coating (cathode) and the pipeline segment where the insulation is damaged in electrolyte (the anode) (Fig. 1).

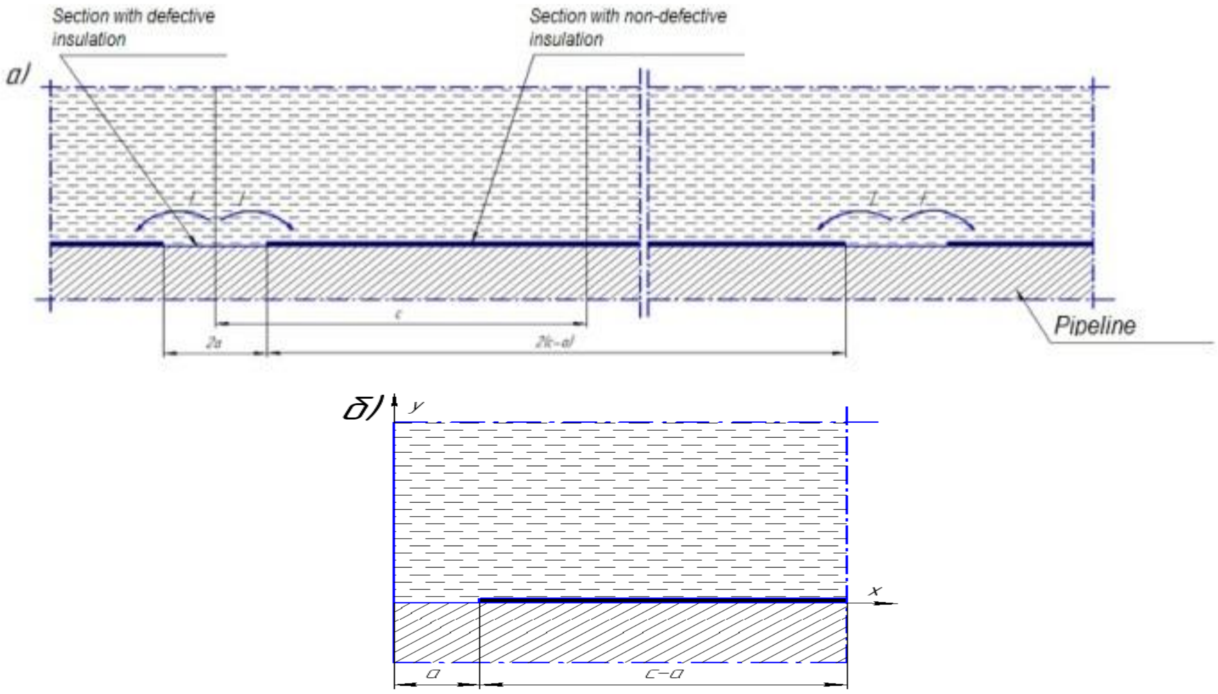

Figure 1. - Local corrosion element in the pipeline under the earth stratum: a) general layout, b) computed model.

Due to the symmetry of the heterogeneous surface's model, it is enough to consider not the entire surface, but only part of it, between the points $x = 0$ and $x = c$, which correspond to the middles of disparate areas, and point a is the boundary between them.

This part of the surface is further understood as a local element.

Determination of the electric field in the system is reduced to solution of the two-dimensional Laplace equation:

$$\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} = 0 \tag{1}$$

Boundary conditions are as follows:

1) at an infinite distance from the electrode (fittings) no excitement is made in the electric field

$$\varphi\ (y \to \infty,\ x) = const; \tag{2}$$

2) the second is the result of the considered model's symmetry

$$\frac{\partial\varphi}{\partial x}\Big|_{x=0} = \frac{\partial\varphi}{\partial x}\Big|_{x=c} = 0\,; \tag{3}$$

3) the conditions in the disparate areas can be presented as follows:

$$\varphi = E_a + L\,\frac{\partial\varphi}{\partial y}\ ,\ \text{where } y = 0;\ 0 \le x < a; \tag{4}$$

$$\varphi = E_{к} + L\frac{\partial\varphi}{\partial y}\ ,\ \text{where } y = 0;\ a \le x \le c, \tag{5}$$

where $L = \gamma{\cdot}b$; b – polarization factor; E_a, $E_к$ – anode and cathode dead potentials.

The solution of equation (1) with the following boundary conditions can be obtained by Euler-Fourier method:

$$\varphi(x,y) = \frac{a\left(E_a - E_K\right) + cE_K}{c} + \sum_{K=1}^{\infty}\frac{2\left(E_a - E_K\right)}{\pi k\left(1 + \frac{\pi k}{c}L\right)}\sin\frac{\pi k}{c}a\cos\frac{\pi k}{c}xe^{-\frac{\pi k}{c}y} =$$

$$= \frac{a\left(E_a - E_K\right) + cE_K}{c} + \frac{2\left(E_a - E_K\right)}{\pi}\sum_{K=1}^{\infty}\frac{\sin\frac{\pi k}{c}a}{\left(1 + \frac{\pi k}{c}L\right)k}\cos\frac{\pi k}{c}xe^{-\frac{\pi k}{c}y}\,. \tag{6}$$

Considering that $i = -\gamma\left(\frac{d\varphi}{dy}\right)_{y=0}$ based on (1) an expression is obtained for determining the current density distribution on the surface of a single local element.

$$i(x) = \frac{2\left(E_a - E_k\right)\gamma}{c}\sum_{k=1}^{\infty}\frac{\sin\frac{\pi k a}{c}\cos\frac{\pi k x}{c}}{k(1 + \frac{\pi k L}{c})}\,. \tag{7}$$

The current density on the local element’s surface varies in length. Integrating the expression from 0 to *a*, we find anodic current of a single element.

$$\int_0^a \cos\frac{\pi k x}{c}dx = \frac{c}{\pi k}\sin\frac{\pi k x}{c}\Bigg|_0^a = \frac{c}{\pi k}\sin\frac{\pi k a}{c}\,. \tag{8}$$

Then the galvanic element’s current will be

$$I = \frac{2\gamma(E_a - E_k)}{\pi}\sum_{k=1}^{\infty}\frac{\sin^2\frac{k\pi a}{c}}{k(1+\frac{\pi k L}{c})}\,,$$

або $$I = \frac{2\gamma(E_a - E_k)}{\pi}\sum_{k=1}^{\infty}\frac{\frac{1-\cos 2\frac{\pi k \alpha}{c}}{2}}{k(1+\frac{\pi k L}{c})}\,. \tag{9}$$

Numerous studies of the present numerical series showed that the series is quickly converging, and for practical calculations it is enough to take three initial members of the present numerical series.

A theoretical study of the obtained mathematical model has been performed, which allowed to conclude the following.

Distribution of current density on the heterogeneous electrode is uneven. The anode (corrosion rate) current density is in its maximum in the middle of the crack. As the anode area is increasing the maximum current density variation between the different areas is decreasing, while its uneven distribution within the same area is increasing. The influence of the anode area (width of cracks) size on the distribution of current on heterogeneous electrode is substantially exceeding its own size.

The main influence on the size and distribution of potential and the corrosion rate is produced by the potential difference on the heterogeneous surface between the cathode and anode areas and by the environment’s electrical conductivity.

Thus, environmental safety of oil pipelines operation largely depends on the metal’s corrosion resistance. The problem of modeling the pipeline metal’s electrochemical corrosion in the damaged insulation area under the electrolytic environment action is solved. It comes to determining the static electrical field that occurs when macrogalvanic couples operate with the anode in the site with the damaged insulation, and with the cathode in the area under the insulation cover.

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Анотація. Розв’язана задача моделювання електрохімічної корозії ділянки трубопроводу в тріщині ізоляційного покриття при дії агресивного по відношенню до металу трубопроводу електролітичного середовиша, котра зводиться до визначення стаціонарного електричного поля, що виникає при роботі гальванопари з анодом на ділянці трубопроводу в тріщині і катодом на ділянці трубопроводу під ізоляційним покриттям. Перевагою даної моделі є можливість прогнозування розвитку корозії трубопроводу за часом, що є важливим при визначенні залишкового ресурсу конструкції. Розподіл потенціалу електричного поля визначено шляхом розв’язання двохмірного диференціального рівняння Лапласа із заданими граничними умовами, що дозволило отримати функціональні залежності для розрахунків щільності струму (швидкості корозії) та електричного струму діючої гальванопари «метал в тріщині – метал під ізоляційним покриттям».

Ключові слова: електрохімічна корозія, підземні трубопроводи, струм корозії.

Аннотация. Решена задача моделирования электрохимической коррозии участка трубопровода в трещине изоляционного покрытия под действием агрессивной по отношению к металлу трубопровода электролитической среды, которая сводится к определению стационарного электролитического поля, которое возникает при работе гальванопары с анодом на участке трубопровода в трещине и катодом на участке трубопровода под изоляционным покрытием. Преимуществом данной модели является возможность прогнозирования развития коррозии трубопровода со временем, что является важным при определении остаточного ресурса конструкции. Распределение потенциала электрического поля определено решением двухмерного дифференциального уравнения Лапласа с заданными граничными условиями, что позволило получить функциональные зависимости для расчетов плотностей тока (скорости коррозии) и электрического тока действующей гальванопары «металл в трещине – металл под изоляционным покрытием».

Ключевые слова: электрохимическая коррозия, подземные трубопроводы, ток коррозии.

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