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Research paper

Calculation of Steel Pipeline Corrosion Depth at the Galvanic Corrosive Element Operation

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Abstract

The work is devoted to the issue of calculating the safe life of steel pipelines, which is in accordance with the definition of the residual thickness of the pipe wall.

The purpose of this work is to develop a dependence, permitting to calculate the corrosion depth of the steel pipeline in the crack of the insulation coating under the action of an electrolytic medium aggressive to the pipeline metal. To achieve this goal, the following tasks were solved: to develop a dependence based on the mathematical model of a local corrosion element, that would allow to calculate the steel pipeline corrosion depth in the crack of the insulating coating, which would be based on real parameters obtained during the structures examination; to conduct an experimental verification of the steel pipeline's corrosion damage depth during the galvanic corrosion element's operation.

Based on the mathematical model of the pipeline's electrochemical corrosion in the crack of the insulating coating under the action of an the electrolytic medium aggressive to the pipeline metal, a dependence was obtained permitting to calculate the depth of the pipeline's wall corrosion during the work of the macro-galvanic corrosion couples and the stable presence of an aggressive solution in the damaged zone. The experimental studies have proved that direct corrosion tests are consistent with the design values of the macro-galvanic couple's current. The advantage of this model is the ability to predict the development of corrosion in time, regardless of the aggressive electrolyte's chemical composition, the possibility of obtaining the required calculation parameters using the structures operated.

Keywords: *steel oil pipeline, electrolytic corrosion, galvanic element, corrosion rate, corrosion depth.*

1. Introduction

Ukraine has a developed network of main oil pipelines, oil product pipelines and gas pipelines, the average operating life of which is exceeding 30 years. The first built oil pipelines operate over 48 years [1, 2].

The operating life of the main gas and oil pipelines system in Ukraine in many cases is approaching the planned one. The numerous corrosion damages to the exterior pipelines' surfaces aggravate the problem of further efficient and safe operation of pipelines. With the increase of their lifetime, the problem of efficient and continuous pipeline transport operation becomes ever more relevant, ensured by the organization of periodical technical diagnostics of the pipeline elements condition and repair in the places of detected inadmissible defects.

The long-term operation of pipelines, starting from the transport and storage of pipes, causes various types of damages to them, namely: damage to insulation, corrosion damages, dints in the pipe metal, cracks in welds of prolonged use and cracks near welds. Such damages in contact with external technological environments results in corrosion, mechanical and corrosion-mechanical processes leading to the destruction of pipes [4].

Analysis of the reasons for the pipelines failures shows that the damages most frequently occurring on steel tubes are fistulas caused by the influence of pipes corrosion [5, 6]. The process of the design resource working out proceeds against the background of the developing electrochemical pipe metal's corrosion, which reduces the thickness of the structure's wall, and hence a decrease in the design resource.

Failures and accidents due to corrosion are explained by the low quality of insulating materials used construction industry in previous years, and by imperfection of the protection systems.

One of the ways to improve the environmental safety and the operation lifetime of oil pipelines is to take into account the factors characterizing the corrosion processes on the pipelines' metal, thus preventing the formation of cracks on the surface and the outflow of oil.

It is clear that the resource under conditions of electrolytic solutions action will determine corrosion in cracks of steel, which has a direct contact with aggressive environment.

Separate methods for assessing the residual life, durability of steel transport structures operating in aggressive environments are based on calculations that do not take into account the characteristics of corrosion processes in the construction divisions. Corrosive processes on steel divisions are represented mainly by empirical dependencies, which are not associated with the presence of cracks in the insulation coatings.

Proceeding from the above, ensuring the ecological safety of the oil pipeline division's operation by monitoring the electrochemical parameters of corrosion in the pipeline divisions is relevant. The issues of the effective steel pipes' residual life calculation comply with the definition of the pipeline wall's thickness. The urgency of such tasks is beyond doubt in many regions of the world.

Moreover, one of the priorities in the XXI century is the problem of environmental safety and environmental monitoring. Hence the main task is to ensure the reliability and safety of pipeline systems.

2. Main body

Studying the oil transportation system of Ukraine, the authors [7] stated that its reliable and safe operation is only possible with the appropriate scientific and technical support. The problem of reliability should take the lead in the international and national legislations.

In the works [8, 9] the factors of oil pipelines reliability and resources of the underground geological space of Ukraine, the process of main oil pipelines corrosion in soil conditions were studied, issues of underground objects operation, the state of the linear part in the oil transport system of Ukraine were analyzed. The results of the researchers' studies prove the relevance of the research line.

As it is commonly known, the reliability of pipelines is laid at the design stage. The calculation of the structural strength on the basis of the methods of building mechanics with the use of stock factors can not fully take into account the variety of conditions of operation of the structure.

The application of aerospace methods for controlling the state of the pipeline, the intrinsic magnetic and ultrasound flaw detectors of the new generation definitely gives a picture of the actual state of the building and allows warning of the possibility of emergency situations. But conducting such monitoring is quite costly.

One of the ways to increase the ecological safety of Ukrainian oil pipelines exploitation is to take into account the factors characterizing precisely the corrosion processes on the metal pipelines, thus predicting the development of cracks on the surface.

Periodic diagnostic survey of oil pipelines allows to predict the growth of the corrosive damage depth and to prevent possible emergency situations on separate linear sections [10].

The main role in ensuring the environmental safety of pipelines exploitation under the conditions of corrosion damage (cracks) development belongs to the study of corrosion depth and dynamics.

A well-known method [11] for predicting the dynamics of the corrosion depth in pipelines is based on two or more measurements of wall thickness. But this model does not take into account the conditions for the corrosion occurrence.

The authors [12] use the following expression to determine the wall thickness and to calculate the corrosion depth

$$\ln \Delta S = \alpha - \beta T^{-1} + (\gamma + \varepsilon T)\ln \tau, \tag{1}$$

where ΔS –corrosion depth per hour τ, mm (mm);

τ – time, hour (hours);

T –absolute temperature of the metal on the pipe's surface, К;

α, β, γ, ε –coefficients, depending on the material the pipe is made of, the type of raw material etc.

Such methods for assessing the corrosion damage depth on transporting constructions sections operating in aggressive environments are based on calculations that do not take into account the corrosion processes' characteristics. Corrosion processes on steel sections are expressed mainly by empirical dependencies, which are not associated with the presence of cracks in the insulation coatings.

In the published works containing descriptions of the methods for calculating the rates of corrosion wear on the basis of operational control data, it is noted that the calculation is empirical. The studied methods take into account factors that significantly increase the calculating error [13–16].

It has been proved by researchers that the main role in assessing the safety of pipelines operation in the presence of cracks in the insulation coating belongs to studies of the corrosion rate and depth.

The known methods of assessing the condition of metal as a result of corrosion tests require the use of quantitative indicators [17, 18]. The weight index of corrosion is defined as the ratio of mass loss to the surface of the sample per a time unit. The corrosion depth index is used for the assessment of both continuous and local corrosion. The volumetric corrosion index can be determined by the volume of the liberated gases in relation to the surface of the sample for a certain period of time.

Taking into account that the corrosion of steel with cracks is of the electrochemical nature, recent developments in the corrosion losses calculation are more targeted to the use of electrochemical and electrical parameters, such as the density of the corrosion current, the electrode potential, the metal polarization in cracks, electric resistance of insulating coating. The advantage here is that these parameters can be obtained directly on the structures that are operated.

The way to trouble-free pipeline operation technology may be to monitor and control the electrochemical parameters characterizing the process of steel electro-chemical corrosion.

It is known from practical electrochemistry, that search for corrosion characteristics on metal in an electrolytic medium can be reduced to determination of the electric potential distribution and the current on its surface [19]. This makes it possible, when studying the pipeline steel corrosion in cracks, to use common approaches to calculations of stationary electric fields, developed in theoretical electrical engineering and in branches of mathematical physics.

Thus, despite numerous studies, the need to develop new dependencies for the assessment of corrosive processes that take into account local environmental impacts, particularly on operation of oil pipelines, remains topical.

Prolonged interaction of the metal pipe with the environment leads to the corrosion processes intensification, to the degradation of physical and mechanical properties of the pipe wall's material [3]. Designed and manufactured in accordance with the requirements of normative documents pipelines must be resistant to the environment. But manufacturing defects and damages contribute to the initiation and development of corrosion processes on pipelines [4]. As a result, the risk of accident hazards grows, which adversely affects the environmental safety of the oil pipelines operation. Exploitation of oil pipelines is inextricably linked with the corrosive destruction of oil and gas equipment, particularly industrial pipelines.

The study of the conditions of pipelines operation in the soil ground shows that, despite the use of various measures, the number of accidents on pipelines due to corrosion is about 27% of the total.

The problem lies in ensuring the technical reliability and safe operation of pipelines with the use of technical diagnostics methods, particularly corrosion defects, as well as the development of efficient methods for assessing the working capacity of the exploited material. In solving such problems an important role is played by determining the depth of corrosion damage, because in the calculations of the residual resource, it is necessary to take into account the current condition of the exploited metal.

The pipeline, lying in the ground, is exposed to corrosive aggressive conditions. Virtually no insulation coating ensures full protection of the underground pipeline which is explained by defects in the coating itself, due to which an electrochemical contact is established between the pipe and the electrolyte.

In addition, sometimes the insulating coating loses its protective properties, that is, processes of its degradation are taking place. The actual operation lifetime of polymeric banded insulation materials is 8-12 years.

In many review articles [20] it is shown that in 70% of cases corrosion of underground pipelines is the evenness failure (destruction).

The residual resource is understood as the pipeline’s operation time from the moment of its diagnosis to reaching the critical state. Residual resource as a random variable is characterized by a numerical parameter of the operation time and the probability that during this time the critical state will not be reached. One of the factors that determines the residual lifetime of a construction are the indices of the object’s technical condition and the parameters changes of which may lead to the critical state, namely: the residual thickness of the pipe wall and the rate of this parameter changes during further diagnostics and the pipeline network operation.

Therefore, it is the issue of calculating the degree of the pipeline corrosion damage, namely determination of the corrosion depth due to electrochemical corrosion that this article is devoted to.

In underground pipelines with areas where insulation is damaged, the anode and cathode polarization characteristics of steel are significantly changed and as a consequence steel potentials in these areas are changed, too. Such areas significantly influence the development of the pipeline’s corrosion, creating conditions for emergence of macro corrosion pair couples.

In view of the fact that exploitation of the oil pipeline with sites where the broken insulation is associated with the electrochemical corrosion of the pipeline metal, the attention should be paid to determining characteristics of the corrosion process when examining the pipeline. The current of the given galvanic couples is a universal indicator for calculating metal losses in cracks.

The insulating coating like a capillary-porous material is a second class conductor, therefore the process of steel corrosion in it can be considered from the positions of the ordinary electrochemical corrosion of metals in electrolytes. In most cases, which can include pipeline’s corrosion in the crack, heterogenous mechanism of metal destruction dominates where separate parts of the metal surface are cathodes (pipeline under the insulation layer), and the other anodes (pipeline in the crack).

In this formulation, the problem of the pipeline section’s electrochemical corrosion is reduced to determining the stationary electrical field that occurs when a galvanic couple is operating with a heterogeneous electrode. Thus, the recording of the equations and formulas of the boundary conditions that answers the potential of this field.

The main characteristic of the electric field is the potential for which it is possible to find the corrosion current density according to the known Ohm law in the differential form:

$$i = \gamma \frac{\partial \varphi}{\partial N} \tag{2}$$

where γ –conductivity of electrolytic medium;
N –normal to the surface of the corroded metal;
φ –potential.

Let us consider an electric field near a heterogeneous electrode whose model consists of 2 sections of arbitrary width that differ in stationary potentials.

The local corrosion element is represented by a section from a pipeline under an insulating coating (cathode) and a section with a pipeline in a crack under an electrolyte (anode) (Fig. 1).

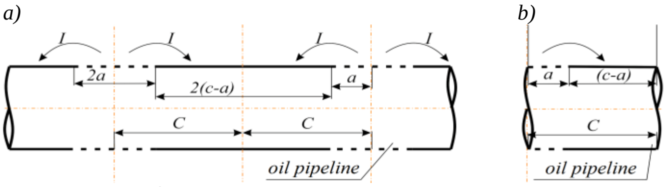


Fig. 1: Scheme of a local corrosion element on a pipeline in an insulating coating with a crack: a – general view; b – designed model, c – distance between the middle of the sections; 2a – width of the abnormal area; 2 (c – a) – width of cathode area; 1 – pipeline; 2 – insulating coating; 3 – crack; 4 – electrolytic medium (aggressive liquid)

The definition of the electric field’s potential distribution in this case can be reduced to the solution of the two-dimensional Laplace equation:

$$\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} = 0, \tag{3}$$

where φ – potential;
x, y –current coordinates.

The boundary conditions are as follows:
1) at the infinite distance from the electrode’s surface (oil-water), no excitement in the electric field is introduced:

$\varphi\ (y \to \infty, x) = const;$

2) the second is a consequence of the of the considered model’s symmetry:

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

3) the conditions in uneven sectors can be represented as:

$\varphi=E_a+Ld\varphi/dy$ *with* $y=0,\ 0\le x<a$;

$\varphi=E_k+Ld\varphi/dy$ *with* $y=0,\ a\le x<c$;

where $L=\gamma \cdot b$; γ –specific conductivity of electrolyte; b – polarization coefficient; E_a, $E_к$ – electrically dead potentials of anode and cathode, mV.

The solution of equation (3) under these boundary conditions can be obtained by the Euler-Fourier method. The task is reduced to these functions. As a result of long transformations, we obtain:

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

$$=\frac{a(E_a-E_K)+cE_K}{c}+\frac{2(E_a-E_K)}{\pi}\sum_{K=1}^{\infty}\frac{\sin\frac{\pi k}{c}a}{\left(1+\frac{\pi k}{c}L\right)k}\cos\frac{\pi k}{c}xe^{-\frac{\pi k}{c}y}. \tag{4}$$

given that $i=-\gamma\left(\frac{d\varphi}{dy}\right)_{y=0}$ we obtain the equation determining the distribution of current density on the surface of one local element: Taking into account that $i=-\gamma\left(\frac{d\varphi}{dy}\right)_{y=0}$ we obtain an equation for determining the current density distribution on the surface of one local element:

$$i(x)=\frac{2(E_a-E_k)\gamma}{c}\sum_{k=1}^{\infty}\frac{\sin\frac{\pi ka}{c}\cos\frac{\pi kx}{c}}{k(1+\frac{\pi kL}{c})}. \tag{5}$$

The current density on the surface of the local element changesalong the length. Integrating the expression from 0 to *a*, we find the anode current of one element [21]:

$$\int_0^a \cos\frac{\pi kx}{c}dx = \frac{c}{\pi k}\sin\frac{\pi kx}{c}\Big|_0^a = \frac{c}{\pi k}\sin\frac{\pi ka}{c} \qquad (6)$$

Then, the current of the galvanic element will be:

$$I = \frac{2\gamma(E_a - E_k)}{\pi}\sum_{k=1}^{\infty}\frac{\dfrac{1-\cos 2\dfrac{\pi k\alpha}{c}}{2}}{k(1+\dfrac{\pi kL}{c})} \qquad (7)$$

Thus, the problem of the simulating the electrochemical corrosion of steel in the crack of the insulating coating under the action of an aggressive metal-electrolytic medium, which is reduced to the determination of the stationary electric field of the heterogeneous electrode is solved. The advantage of this model is the ability to predict the development of corrosion in time, which is important for determining the residual life of the structure.

The thickness of the pipe wall is one of the main parameters that effects the residual life of the structure. Changing the thickness of the pipeline leads to a change in the distribution of stresses on the pipeline and contributes to the development of environmentally hazardous situations. Thickness of the pipe wall depends on the working pressure of loads, structural characteristics and strength, including the allowance for an even corrosion loss.

In order to calculate the loss of cross-sectional area under the constant presence of an aggressive electrolytic solution in the damaged insulation zone, the dynamics of the corrosion depth h in the pipeline during the galvanic element operation "a pipeline with damaged insulation is a pipeline under the insulating coating" was considered.

$$h = \frac{V}{\pi D_0 a_y} = \frac{KIt}{7{,}87\pi D_0 a_y}, \qquad (8)$$

where V – the volume of the corroded metal in the crack, см^3;

D_0 –initial diameter of the reinforcement bar, cm;

K – electrochemical equivalent, g/A hour;

t – corrosion time, hour;

7,87 – specific weight, density of the reinforcement bar metal, g/cm^3;

I − amperage of the galvanic couple, A;

a_y − length of the length of the pipeline section under the crack in the insulating, which is subject to damage, cm.

Thus, taking into account (7) from the formula (8) we have

$$h = \frac{K}{7{,}87\pi D_0 a_y}\left(\frac{2(E_a - E_k)\gamma}{\pi}\times\sum_{\kappa=1}^{\infty}\frac{\dfrac{1-\cos 2\dfrac{\pi k\alpha}{c}}{2}}{\kappa(1+\dfrac{\kappa\pi L}{c})}\right)t. \qquad (9)$$

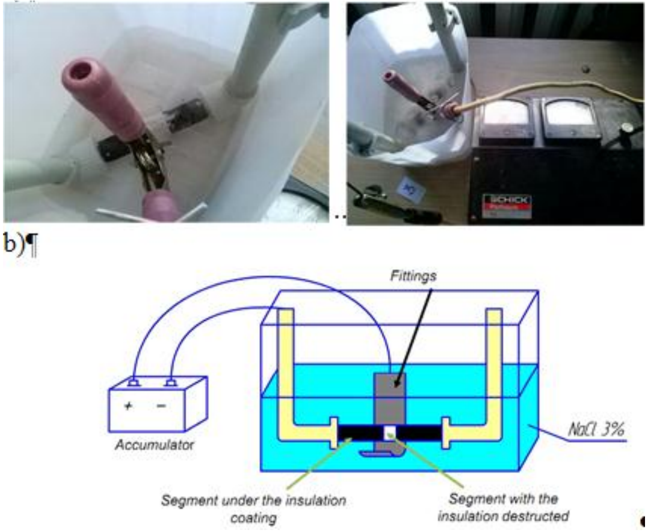
For experimental verification of the suggested method for calculating corrosion losses on the pipeline section during operation of a galvanic couple in soil ground, small reinforcing specimens and steel tubes were investigated.

As part of the pipeline steel cold-rolled wire with a diameter of 1 mm, reinforcement bars of A240 (AI) class with a diameter of 6 mm and steel pipes with an outer diameter of 21,4 mm were used. The samples were covered with paint and varnish coating, and the areas subject to corrosion were exposed in the middle from the paint by a width of 0,5; 1; 1,5 and 2 mm. These bare areas simulated the length of the pipeline section in the zone of the damaged insulation to be destructed. Before painting, the reinforcement bars and pipes were cleaned and weighed with the analytical balance. Separately, reinforcement bars with a diameter of 1 and 6 mm without coloring were prepared. For each width of the areas, three twin-bars and three undamaged bars were made.

The composition of the solutions that come in contact with the structures may be different and in some cases completely unforeseen. Therefore, as an aggressive medium to accelerate corrosion, the 3% solution of NaCl, which is a standard electrolyte in electrochemical studies of metal corrosion, was selected.

Each bar was immersed in the aggressive medium (3% NaCl solution). In order to study the corrosion losses during the macro-galvanic couple's operation in the process of the experiment, a device was constructed consisting of a plastic trough filled with aggressive fluid and the prepared specimens immersed in it (Fig. 2).

a)



b)¶

Fig. 2: Photo (a) and scheme (b) of the experimental unit for testing metal losses

In the course of the experiment, periodic measurements of static potentials of the reinforcement bars at the anode and cathode sections were performed. Copper sulfate and silver chloride electrodes were used as the reference ones.

Specific electrical conductivity of 3% NaCl solution and polarization characteristics of metal reinforcement in 3% NaCl solution were taken from the reference literature and amounted to $\gamma = 0.67$ Ohm^{-1} ·cm^{-1}, $b_a = 2$ Ohm cm^2.

The experiment time for beams with 1 mm diameter bars was 170 hours, and for those with 6 mm diameter bars and with steel tubes - 5328 hours.

In parallel to this experiment, a 3% solution of NaCl was loaded with pre-weighed reinforcement bars with diameters of 1 and 6 mm in order to determine the general corrosion.

After the experiments, the reinforcement bars and tubes were released from the paint, cleaned and weighed. The diameter of the bars on the anode sections and the length of the anode sections were also measured.

Corrosive lesions in the anode sections of galvanic couples were visually detected. Cathodic sections were not damaged.

The results of experimental studies are presented in Figure 3.

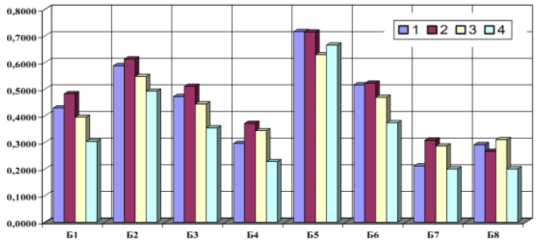


Fig. 3: Comparative diagram of the loss in the cross-sectional area ratio on samples at corrosion: 1 – according to the design value of current v_p; 2 –

according to the weight indices v_e; 3 – according to the depth indices v_h; 4 – by direct measurements of diameters v_d

Thus, experimental studies on small reinforcement bars and steel tubes for calculation of the relative loss of the cross-sectional area of a steel pipe during corrosion in the crack of the insulating coating showed that the direct corrosion tests are consistent with the designed current values of the macro-galvanic couples.

3. Conclusion

Based on the mathematical model of local corrosion element a dependence was developed permitting to calculate the depth of corrosion damage to steel pipeline crack in the coating. The dependence is based on the real parameters obtained during the examination of the structure.

An experimental verification was performed of the steel pipe’s corrosion depth assessment with the galvanic corrosion element operating. The study of the steel pipe’s damage depth calculation in the insulating coating crack showed that direct corrosive test is consistent with the designed values of the macro galvanic couple’s current. The results of the experiment permit to calculate the depth of the pipeline’s corrosion according to the developed methodology, as well as to predict the development of this process.

The study confirms the main role of the macro-galvanic couples in the corrosion losses of steel in the cracks of the insulating coating. The share of corrosion caused by the work of macro galvanic couples in the3% solution of NaCl on the samples under study under the above conditions amounted to 93,57-99,97%.

The dependence permits to predict the development of corrosion in time, regardless of the chemical composition of aggressive electrolytes, the possibility of obtaining the required designed parameters on the structures operated.

References

[1] Polyakov, S., Klimenko, A., Malkova, O. Electrochemical monitoring pipelines for corrosion hazardous areas. *Fiziko-chimichna mekhnanika materialov*, No. 7 , Vol.2, (2008), pp.761 – 766.

[2] Zhdek, A., Hrudz, M. (2012). Determination of residual life long exploited oil, taking into account existing defects and corrosion conditions. *Naukovy visnyk Ivano-Phrankivskogo natsiionalnogo universytetu naphty I hazu*, no. 2(32), 58 – 66.

[3] Rihan Omar Rihan Electrochemical Corrosion Behavior of X52 and X60 Steels in Carbon Dioxide Containing Saltwater Solution (2013).Vol.16(1). 227-236 DDOI: 10.1590/S1516-14392012005000170

[4] Poberezhnyi L. Corrosion monitoring of transit gas pipelines / L.Ya. Poberezhnyi, A.I. Stanetskyi, V.V. Rudko // Bulletin of TNTU. – 2011. – No.3. – P. 20-26. INSPEC

[5] Stepova O. (2011). Technological safety operation of main oil pipelines. Zbirnyk naukovykh prats (galuzeve mashynobuduvannia, budivnytstvo), issue. 2(30), *Poltava: Poltava National Technical Yuri Kondratyk University*. 266 – 269

[6] Stepova, O. (2011). Ensuring environmental safety of oil exploitation by monitoring electrochemical parameters. Zbirnyk naukovykh prats (tekhnichni nauky), issue. 1(53), *Rivne: Natsionalnyi universytet vodnogo hospodarstva*, 201 – 207 .

[7] Becker, M. (2007). Ensuring reliable operation of the system oil transportation. *Sbornik dokladov nauchno-prakticheskogo seminara,* Kyiv, Institute elektrocvarky imeni E.O. Patona, April, 17–18, 2007, 3–5.

[8] Rohoznyuk, B., Guiov, Yu. and Kuzmenko, Yu. (2000). Technical operation of underground corrosion protection of oil pipelines. [Technical operation of underground corrosion protection of oil pipelines], Kyiv: Tehdiagaz.

[9] Kornienko, S. and Kortubyak, O. (2008). Resources space underground geological Ukraine. *Visnyk Kyivskoho universytetu. Seriya: Geologiya* no. 43, 35–37.

[10] Miniailo, I.V. (2009) Determination of corrosion rate of metal pipes on the Urengoy-Chelyabinsk gas pipeline. *News of Higher Educational Establishments. Oil and gas. Publisher: Tyumen Industrial University*. - no6, 52-58.

[11] Instruktsiia po opredeleniiu skorosti korrozii metala stenok korpusov sosudov i truboprovodov na predpriiatiiakh Mynneftekhymproma SSSR (1983) Publisher: Volgograd,124c. URL: http://meganorm.ru/Data2/1/4293801/4293801208.htm

[12] URL: https://all4study.ru/proizvodstvo/raschet-utoneniya-stenki-za-schet-korrozii.html

[13] Bridgeman, J. and Shankar, R. (1991) Erosion-corrosion data handling for reliable NDE. *Nuclear Eng. And Design.* no. 131, 285-297.

[14] H. Lee (2003) Thinned Pipe Management Program of Korean NPPs. S / *Trans. of the 17th Inter. Conf. on Structure Mech. in Reactor Technology (SmiRT 17) Prague, Czech Republic. August 17-22*, 1-8.

[15] Moolayil T.M. (2007) Mitigation of degradation of high energy secondary cycle piping due to FAC and life management in Indian NPPs. *Second international Symposium on Nuclear Power Plant Life Management from 15-18th October, 2007 at Shanghai China,* 48 p.

[16] Baranenko V.I. (2010) Calculation of the rate of erosion-corrosion wear and residual life of pipelines AES. *Proceedings of Higher Educational Institutions. Nuclear energy.* no 2, 55-63

[17] Vorobeva G. (1975). Corrosion resistance of materials in aggressive environments of chemical industries. *Handbook of Chemistry*. M.: Chemistry, 816

[18] Romanov V.V. Methods for studying corrosion of metals (1965) M.: *Metallurgy*, 280

[19] Alekseeva N.V., Strizhevsky I.V. (1989). Mathematical modeling of the distribution of corrosion along the perimeter of the cross-section of the underground pipeline // *Protection of metals.* no 1.

[20] A.I. Elizarov, V.V. Zhurav (2008) About Some Aspects of Slot-Hole Corrosion *Physics and chemistry of solid state* Vol. 9, No 3, P. 635-638 URL:http://www.pu.if.ua/inst/phys_che/start/pcss/vol9/0903-29.pdf

[21] Stepova, O. and Paraschienko, I (2017) Modeling of the corrosion process in steel oil pipelines in order to improve environmental safety *Eastern-European journal of enterprise technologies, industrial and technology systems.* Vol. 2, No 1 (86), 15-20.URL: http://journals.uran.ua/eejet/article/view/96425