

# Corrosive behavior of pipeline steel 17G1C and 13G1C-U in environments NS1-NS3

## Procesy korozyjne stali rurociągowej 17G1C i 13G1C-U w środowiskach NS1-NS3

Miroslava S. Polutrenko, Halyna M. Hrytsuliak, Andriy O. Kotsyubynsky, Uliana B. Andrusiak

*Ivano-Frankivsk National Technical University of Oil and Gas*

**ABSTRACT:** Results of long-term exposure tests (20 months) of 17G1C and 13G1C-U pipeline steel samples in NS1-NS3 model environments (soil electrolyte imitations) are presented in the article. It was established that during the exposure of steel samples in the studied model environments the rate of corrosion processes depends on the component composition of the model environments, the grade of steel and pH. Regardless of the grade of steel, the highest corrosion rate was observed for the NS1 environment, while the corrosion rate for the NS3 environment was almost 21% lower. In the case of the NS2 model environment, the corrosion rate reduction for 17G1C steel was 38.68%, and for 13G1C-U steel – 28.75%, compared to the exposure of these samples in the NS1 environment. The calculated multiple coefficients of determination and linear correlation coefficients indicate a strong relationship between these indicators. The phase composition and structure of corrosion products were determined by the X-ray diffractometer Shimadzu XRD-7000 using the method of X-ray structural analysis. On the basis of the obtained radiographs, the dominant form of iron oxide, which does not depend on the grade of steel, was determined for each environment. The research results have practical value and can be used in predicting the behavior of underground structures in soils of different corrosive activity.

**Key words:** pipe steel, model environment, corrosion rate, radiographs.

**STRESZCZENIE:** W artykule przedstawiono wyniki badań długotrwałej ekspozycji (20 miesięcy) próbek stali rurociągowych 17G1C i 13G1C-U w środowiskach modelowych NS1-NS3 (imitacje elektrolitów glebowych). Na podstawie przeprowadzonych badań stwierdzono, że szybkość procesów korozyjnych zależy od zawartości poszczególnych składników w środowiskach modelowych, jak również od gatunku stali oraz od wielkości pH. Niezależnie od gatunku stali największą szybkość korozji zaobserwowano dla środowiska NS1, podczas gdy szybkość korozji dla środowiska NS3 była niższa o prawie 21%. W przypadku środowiska modelowego NS2 zmniejszenie szybkości korozji dla stali 17G1C wyniosło 38,68%, a dla stali 13G1C-U – 28,75%, w porównaniu do ekspozycji tych próbek w środowisku NS1. Obliczone wielokrotne współczynniki determinacji oraz współczynniki korelacji liniowej wskazują na silny związek między tymi wskaźnikami. Skład fazowy i strukturę produktów korozji określono za pomocą dyfraktometru rentgenowskiego Shimadzu XRD-7000, stosując metodę rentgenowskiej analizy strukturalnej. Na podstawie uzyskanych radiogramów dla każdego ośrodka określono dominującą formę tlenku żelaza, niezależną od gatunku stali. Wyniki badań mają wartość praktyczną i mogą być wykorzystane do przewidywania zachowania się podziemnych konstrukcji stalowych w gruntach o różnej aktywności korozyjnej.

**Słowa kluczowe:** stal rurowa, środowisko modelowe, szybkość korozji, radiogramy.

### Introduction

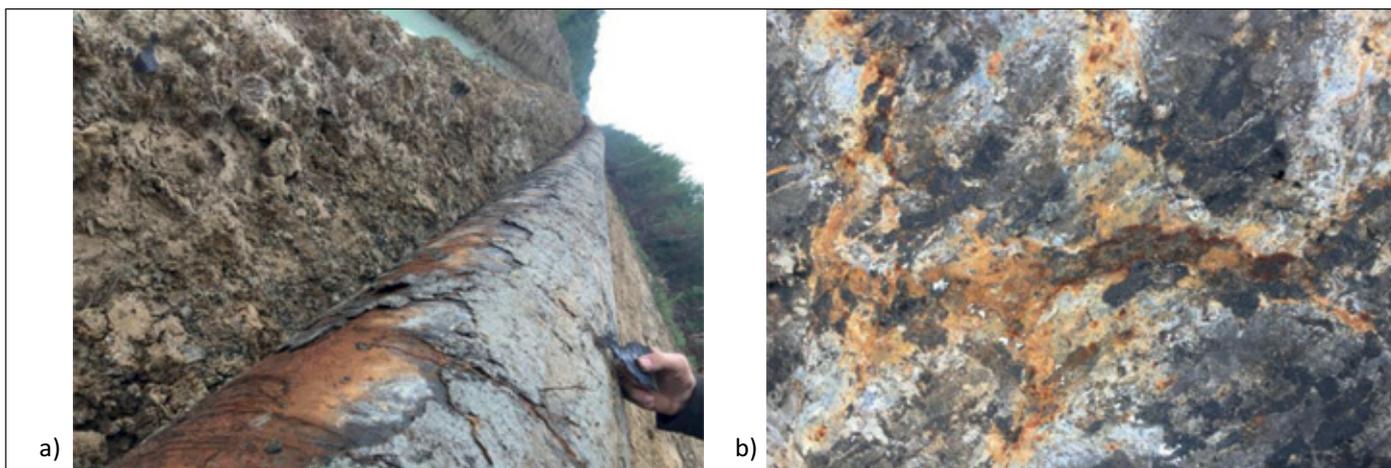
The reliable and efficient operation of Ukraine's pipeline transport in the conditions of martial law is a guarantee of environmental security and energy independence of the country.

Pipelines for the transportation of energy carriers, laid in soils of various corrosive activity, undergo destruction due to exceeding their normative service life (more than 30 years), degradation of the insulating coating, the influence of the

soil electrolyte and the action of the association of microorganisms. All this leads to large material losses and serious environmental consequences. On average, annual losses from corrosion account for 10-15% of the annual budget of an average city (Andreyuk, et al., 1980; Andreykiv et al., 2012; Polutrenko et al., 2022). More than 50% of damage to metal pipeline structures can be attributed to the activity of microorganisms. Despite improvements in protection methods, the length of damaged pipelines in England is increasing annually

Corresponding author: H.M. Hrytsuliak, e-mail: [halyna.hrytsuliak@nung.edu.ua](mailto:halyna.hrytsuliak@nung.edu.ua)

Article contributed to the Editor: 30.12.2022. Approved for publication: 28.03.2023.



**Figure 1.** Corrosion damage to the metal of the pipeline; a) degradation of the insulating coating; b) ulcers on the metal of the pipeline  
**Rysunek 1.** Uszkodzenia korozyjne metalu rurociągu; a) degradacja powłoki izolacyjnej; b) ubytki metalu rurociągu

by 3–4%, especially in silty soils that promote the development of microbiological corrosion. In the USA, biocorrosion of iron pipes, which develops as a result of the activity of sulfate-reducing bacteria, is estimated at \$500 to \$2,000 million per year (Andreykiv, et al., 2012; Kryzhanivsky et al., 2019).

As a result of the degradation of the insulating coating, it cracks and peels off (Gabetta et al., 2008; Xue and Cheng, 2010). The steel of the pipeline is exposed to the corrosive environment, which is represented by the soil electrolyte, ulcers appear on the metal (Figure 1), which can eventually provoke the occurrence of an emergency situation with a leak transported energy carriers.

The corrosive situation of underground pipelines, foundations of buildings and other metal structures operated in the soil is influenced by a large number of factors related to soil and climatic conditions, route features, and operating conditions. Such factors include: soil moisture, chemical and mineral composition (and primarily the amount of dissolved salts in the composition), acidity of the soil electrolyte, soil structure, electrical conductivity, and bacterial composition (Gabetta et al., 2008; Polutrenko et al., 2022).

In order to reduce damages from metal corrosion of underground structures and prevent the occurrence of emergency situations during their operation, scientists are actively continuing research on determining the rate of corrosion processes of various grades of pipe steels in soil electrolytes of different mineralogical composition (Korniyenko and Korbutyak, 2009; Hredil and Tsyurulnyk, 2010; He et al., 2015; Gredil and Tsyurulnik, 2017; Kryzhanivsky et al., 2019; Lopushniak et al., 2022).

The purpose of the work is to study the corrosion behavior of pipe steels 17G1S and St. 13G1S-U in model environments NS1–NS3, as imitations of soil electrolyte.

## Materials and methods

Samples of tubular steel 17G1S and steel 13G1S-U with dimensions of  $10 \times 50 \times 1.0$  mm were selected as the object of the study.

During the research, conditions similar to the operating conditions of main pipelines on the territory of Ukraine were modeled. The research was conducted in 3 compositions of model soil electrolyte environments NS1, NS2 and NS3 (Figure 2). The hydrogen index of the media (pH) was determined using a pH meter of the MI-1500 brand. At the end of the research, the metal samples were subjected to mechanical and chemical processing to remove corrosion products from their surface. The phase composition and structure of corrosion products were analyzed by X-ray analysis using a Shimadzu XRD-7000 X-ray diffractometer (CuK $\alpha$  radiation was used with  $2\theta$  scanning from  $10^\circ$  to  $60^\circ$ ,  $2^\circ$  per minute with a step of  $0.02^\circ$ ). Processing of diffraction patterns involved Rietveld analysis (Match!/FullProf software) (Gabetta et al., 2008; Gredil et al., 2017; Polutrenko et al., 2022).

**Table 1.** Composition of model environments

**Tabela 1.** Składy środowisk modelowych

| Model environment | Composition [mM] |                    |                                     |                                     |
|-------------------|------------------|--------------------|-------------------------------------|-------------------------------------|
|                   | KCl              | NaHCO <sub>3</sub> | CaCl <sub>2</sub> 2H <sub>2</sub> O | MgSO <sub>4</sub> 7H <sub>2</sub> O |
| NS1               | 1.999            | 5.990              | 1.082                               | 0.430                               |
| NS2               | 1.905            | 12.868             | 0.497                               | 1.031                               |
| NS3               | 0.496            |                    | 6.654                               | 0.054                               |

After the tests, brown-brown to black corrosion products were observed on the samples, which uniformly covered the surface and settled on the bottom of the vessel (Figure 2a). The product layer was easily removed mechanically (Figure 2b).



**Figure 2.** Examples of studied compositions of model environments  
**Rysunek 2.** Przykłady badanych składów środowisk modelowych

The rate of corrosion of metal samples was determined by the gravimetric indicator of the rate of corrosion:

$$K_{gr} = (m - m_0) / S / \tau \text{ [mg/dm}^2\text{/day]}$$

where:

$m$  – final mass of the sample [mg],

$m_0$  – mass of the sample before corrosion [mg],

$S$  – surface area of the sample [dm<sup>2</sup>],

$\tau$  – exposure time [day].

## Results and discussion

It was established that during the exposure of steel samples in the studied model environments (20 months), the rate of corrosion processes depends on the component composition of the model environments, the grade of steel and pH. The analysis of the obtained experimental data on the determination of the rate of corrosive damage of steel samples in the studied model environments showed interesting dependencies, presented in Figures 3 and 4.

The corrosion rate for the NS3 medium was 21% lower. In the case of NS2 model environment, the reduction in corrosion rate for steel 13G1S-U was 28.75%, while for steel 17G1S – 38.68%. These patterns are probably related to the fact that even with a slight shift in pH to the alkaline region, only part of the dissolved oxygen is bound by iron oxide ions, which leads to inhibition of the corrosion rate.

Based on previous studies (Gabetta et al., 2008; Polutrenko et al., 2022), we determined the phase composition of corrosion products of 17G1S and 13G1S-U pipe steels, represented by various iron oxides, in NS1 and NS2 model environments, which differed significantly in general mineralization, based on X-ray analysis data. Regardless of the grade of steel, the composition of corrosion products in the NS1 environment was mainly characterized by the presence of lepidocrocite ( $\gamma$ -FeOOH), and in NS2 environment – goethite ( $\alpha$ -FeOOH). The composition of the corrosion products of the studied grades

of steel in NS3 environment, which in general mineralization was close to NS1 environment, turned out to be interesting. The total mineralization of the NS2 medium was more than twice (2.15) the total mineralization of the NS3 model medium (Polutrenko et al., 2018; Hredil et al., 2010).

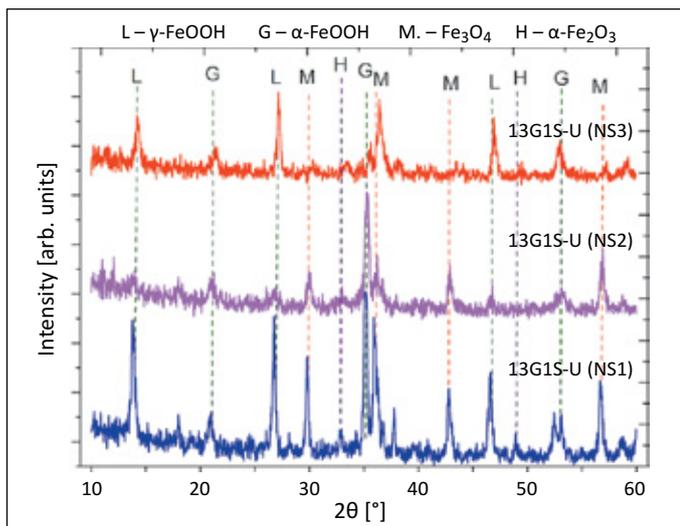
The analysis of the obtained radiographs showed that the corrosion products of the 17G1S and 13G1S-U pipe steels are represented by various iron oxides – with the structure of lepidocrocite, goethite, magnetite, and hematite. The composition of corrosion products varied depending on the mineralization of the medium. Thus, for 13G1S-U steel, the composition of corrosion products in NS1 environment was mainly characterized by the presence of crystals with the structure of lepidocrocite ( $\gamma$ -FeOOH) and magnetite ( $\text{Fe}_3\text{O}_4$ ), in NS2 environment – goethite ( $\alpha$ -FeOOH) and magnetite ( $\text{Fe}_3\text{O}_4$ ), while in NS3 environment by the dominance of lepidocrocite, small amounts of magnetite and trace amounts of goethite (Figure 3).

A slightly different picture of the nature of corrosion products is observed for 17G1S steel (Figure 4) (Korniyenko et al., 2009; Polutrenko et al., 2022).

In NS1 environment, crystals with the structure of lepidocrocite and goethite prevail among the corrosion products, and magnetite is also present. Similar to NS1, the distribution of corrosion products in NS3 environment was observed. In NS2 environment, the distribution of corrosion products was significantly different from what was characteristic of NS1 and NS3. In this case, the presence of goethite and small amounts of magnetite was observed (Korniyenko et al., 2009; Hredil et al., 2010; Polutrenko et al., 2022).

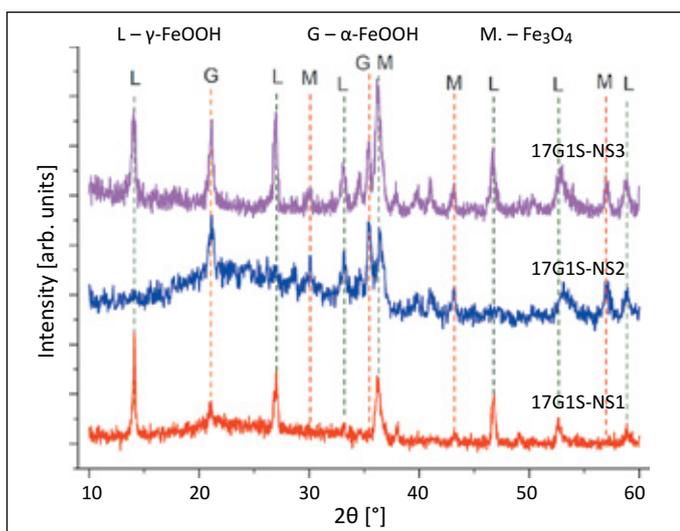
It was established that during the exposure of steel samples in the studied model environments, the rate of corrosion processes depends on the component composition of the model environments, the grade of steel and pH (Table 2).

Based on the data (Table 1), models of dependences of the corrosion rate on the final pH of steel samples and the composition of the model environment for the investigated steel grades were developed (Figures 5–6).



**Figure 3.** Radiographs of corrosion products of 17G1S-U steel samples in NS1–NS3 environments

**Rysunek 3.** Radiogramy produktów korozji próbek stali 17G1S-U w środowiskach NS1-NS3



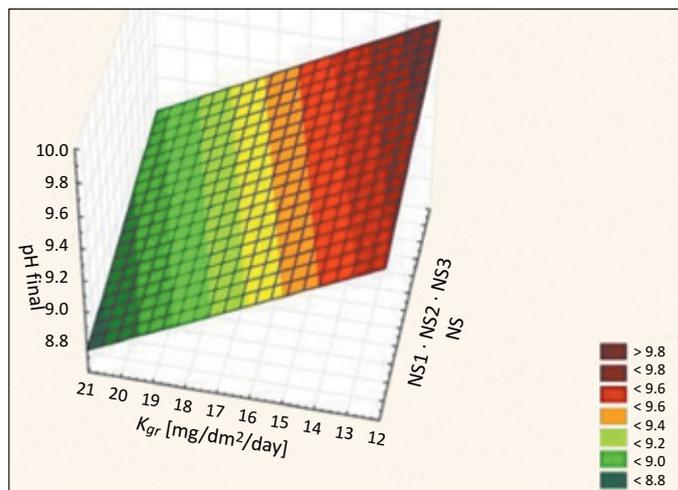
**Figure 4.** Radiographs of corrosion products of 17G1S steel samples in NS1–NS3 environments

**Rysunek 4.** Radiogramy produktów korozji próbek stali 17G1S w środowiskach NS1-NS3

**Table 2.** Influence of the composition of model environments and pH on the corrosion rate of steel samples (Polutrenko et al., 2022)

**Tabela 2.** Wpływ składu środowisk modelowych i pH na szybkość korozji próbek stalowych (Polutrenko et al., 2022)

| Steel brand | Environment | Initial pH | Final pH | $K_{gr}$ [mg/dm <sup>2</sup> /day] |
|-------------|-------------|------------|----------|------------------------------------|
| 17G1S       | NS1         | 7.80       | 8.81     | 20.53                              |
|             | NS2         | 8.87       | 9.64     | 12.59                              |
|             | NS3         | 8.74       | 9.36     | 16.09                              |
| 13G1S-U     | NS1         | 7.80       | 8.62     | 22.33                              |
|             | NS2         | 8.87       | 9.72     | 15.91                              |
|             | NS3         | 8.74       | 9.24     | 17.54                              |



**Figure 5.** The model of dependence of the final pH on the corrosion rate of steel samples and the model environment for the 17G1S steel grade

**Rysunek 5.** Model zależności końcowego pH od szybkości korozji próbek stali i środowiska modelowego dla gatunku stali 17G1S

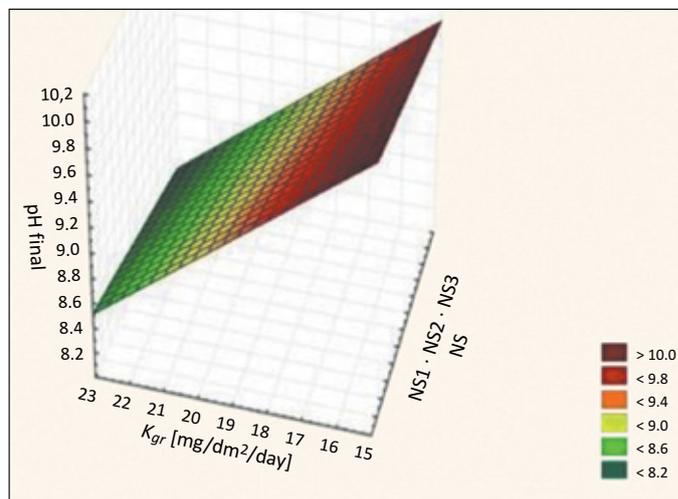
$$z = 10,606 + 0,09441 \cdot x - 0,0921y$$

where  $z$  is the final pH,

$x$  – corrosion rates of steel samples,

$y$  – model environment for steel grade 17G1S.

Multiple coefficient of determination ( $R^2 = 0.71$ ), linear correlation coefficient ( $r = 80$ ) indicate a strong relationship between these indicators (Lopushniak et al., 2022).



**Figure 6.** The model of dependence of final pH on the corrosion rate of steel samples and the model environment for the 13G1S-U steel grade

**Rysunek 6.** Model zależności pH końcowego od szybkości korozji próbek stali i środowiska modelowego dla gatunku stali 13G1S-U

$$z = 13,224 - 0,1631 \cdot x - 0,199y$$

where  $z$  is the final pH,

$x$  – corrosion rates of steel samples,

$y$  – model environment for steel grade 13G1S-U.

Multiple coefficient of determination ( $R^2 = 0.76$ ), linear correlation coefficient ( $r = 87$ ) indicate a strong relationship between these indicators (Lopushniak et al., 2022).

### Conclusions

1. The corrosive behavior of pipeline steels 17G1S and 13G1S-U in NS1–NS3 model environments– soil electrolyte imitations – was studied.
2. It was established that the rate of corrosive processes depends on the component composition of model environments, the grade of steel and pH.
3. Models of dependences of final pH on the rate of corrosion of steel samples and the composition of the model medium for the investigated steel grades were built. The calculated multiple coefficients of determination and linear correlation coefficients indicate a strong relationship between these indicators.
4. The phase composition and structure of corrosion products were determined by X-ray diffractometer Shimadzu XRD-7000 using the method of X-ray structural analysis. On the basis of the obtained radiographs, the dominant form of iron oxide, which does not depend on the grade of steel, was determined for each environment.
5. Research results have practical value and can be used in predicting the behavior of underground structures in soils of different corrosive activity.

### References

- Andreykiv O.Ye., Hembara O.V., Tsyryl'nyk O.T., Nyrkova L.I., 2012. Rozrakhunok zalyshkovoyi dovhovichnosti tryvalo ekspluato-vanoyi dilyanky mahistral'noho hazoprovodu. *Fizyko-Khimichna Mekhanika Materialiv*. 48(2): 103–110.
- Andreyuk E.I., Bilay V.I., Koval E.Z., Kozlova I.A., 1980. Microbial corrosion and its pathogens. *Nauk. Dumka, Kyiv*, 288.
- Gabetta G., Nykyforchyn H.M., Lunarska E., Zonta P.P., Tsyryl'nyk O.T., Nikiforov K., Hredil M.I., Petryna D.Yu., Vuherer T., 2008. In-service degradation of gastrunk pipeline X52 steel. *Fizyko-Khimichna Mekhanika Materialiv*, 1: 88–99.
- Gredil M.I., Tsyryl'nyk O.T., 2017. Peculiarities of corrosion-mechanical rusting have been used to exploit pipeline steels in the model soil. IRTC. Support of materials for the hour of operation, methods of diagnostics and forecasting. *TNTU*, 23–26.
- He B., Han P.J., Lu C.H., Bai X.H., 2015. Effect of soil particle size on the electrochemical corrosion behavior of pipeline steel in saline solution. *Physico Chemical Mechanics of Materials*, 51(6): 124–135.
- Hredil M., Tsyryl'nyk O., 2010. Inner corrosion as a factor of in-bulk steel degradation of transit gas pipelines. *Proc. of the 18<sup>th</sup> European Conference on Fracture (ECF-18), Dresden, Germany*, 30.08–03.09. No. 483.
- Korniyenko S.V., Korbutyak O.M., 2009. Problemy vplyvu hruntovoho seredovyscha na koroziyu mahistral'nykh hazoprovodiv Ukrainy. *Visnyk Kyiv. un-tu. Seriya "Heolohiya"*. 46: 42–43.
- Kryzhanivsky E.I., Polutrenko M.S., Marushchak P.O., Zakiyev I.M., 2019. Biocorrosion and localization of degradation processes on the steel surface of the main gas pipeline. *Physico-Chemical Mechanics of Materials*, 55(5): 66–74.
- Lopushniak V., Hrytsuliak H., Polutrenko M., Lopushniak H., Voloshyn Y., Kotsyubynska Y., Baran B., 2022. Model of Biomass Productivity Under the Influence of Change in the Phytotoxicity of Podzol Soil Due to Reintroduction of Sewage Sludge under Energy Willow. *Journal of Ecological Engineering*, 23(12): 217–226. DOI: 10.12911/22998993/154773.
- Polutrenko M., Fedorovich Y., Hrytsulyak, H., Kotsyubynsky A., 2022. Influence of Composition of Soil Electrolyte Model Environments on Corrosion Rate of Tube Steel. *Ecological Engineering and Environmental Technology*, 23(5): 20–24. DOI: 10.12912/27197050/151633.
- Polutrenko M., Maruschak P., Tymoschenko A., Sorochak A., 2018. Influence of soil microorganisms on metal corrosion of underground pipelines. *KOM – Corrosion and Material Protection Journal*, 62(2): 65–70. DOI: 10.1515/kom-2018-0009.
- Xue H.B., Cheng Y.E., 2010. Electrochemical corrosion behavior of X80 pipeline steel in a near-neutral pH solution. *Materials and Corrosion*, 61(9): 756–761. DOI: 10.1002/maco.200905430



Miroslava Stepanivna POLUTRENKO, Sc.D.  
Professor; Head of the Department of Environmental Protection Technology  
Ivano-Frankivsk National Technical University of Oil and Gas  
15 Karpatska St., Ivano-Frankivsk, 76019, Ukraine  
E-mail: [myroslava.polutrenko@nung.edu.ua](mailto:myroslava.polutrenko@nung.edu.ua)



Andriy Olegovich KOTSYUBYNSKY, Ph.D.  
Department of Environmental Protection Technology  
Ivano-Frankivsk National Technical University of Oil and Gas  
15 Karpatska St., Ivano-Frankivsk, 76019, Ukraine  
E-mail: [a.kotsyubynsky@nung.edu.ua](mailto:a.kotsyubynsky@nung.edu.ua)



Halyna Mikhaailivna HRYTSULIAK, Ph.D.  
Associate Professor at the Department of Environmental Protection Technology  
Ivano-Frankivsk National Technical University of Oil and Gas  
15 Karpatska St., Ivano-Frankivsk, 76019, Ukraine  
E-mail: [halyna.hrytsuliak@nung.edu.ua](mailto:halyna.hrytsuliak@nung.edu.ua)



Uliana Bogdanivna ANDRUSIAK, M.Sc.  
Associate Professor at the Department of Architecture and Urban Planning  
Ivano-Frankivsk National Technical University of Oil and Gas  
15 Karpatska St., Ivano-Frankivsk, 76019, Ukraine  
E-mail: [Ulyana.polutrenko@gmail.com](mailto:Ulyana.polutrenko@gmail.com)