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Determination of conditions for loss of bearing capacity of underground ammonia pipelines based on the monitoring data and flexible search algorithms

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ABSTRACT

Purpose: The study aims to diagnose the corrosion current density in the coating defect on the outer surface of the ammonia pipe depending on the distance to the pumping station, taking into account the interaction of media at the soil-steel interface and using modern graphical data visualization technologies and approaches to model such a system.

Design/methodology/approach: The use of an automated system for monitoring defects in underground metallic components of structures, in particular in ammonia pipelines, is proposed. The use of the information processing approach opens additional opportunities in solving the problem of defect detection. Temperature and pressure indicators in the pipeline play an important role because these parameters must be taken into account in the ammonia pipeline for safe transportation. The analysis of diagnostic signs on the outer surface of the underground metallic ammonia pipeline is carried out taking into account temperature changes and corrosion currents. The parameters and relations of the mathematical model for the description of the influence of thermal processes and mechanical loading in the vicinity of pumping stations on the corresponding corrosion currents in the metal of the ammonia pipeline are offered.

Findings: The paper evaluates the corrosion current density in the coating defect on the metal surface depending on the distance to the pumping station and the relationship between the corrosion current density and the characteristics of the temperature field at a distance L = 0…20 km from the pumping station. The relative density of corrosion current is also compared with the energy characteristics of the surface layers at a distance L = 0…20 km from the pumping station. An information system using cloud technologies for data processing and visualization has been developed, which simplifies the process of data analysis regarding corrosion currents on the metal surface of an ammonia pipeline.

Research limitations/implications: The study was conducted for the section from the pumping station to the pipeline directly on a relatively small data set.

Practical implications: The use of client-server architecture has become very popular, thanks to which monitoring can be carried out in any corner of the planet, using Internet data transmission protocols. At the same time, cloud technologies allow you to deploy such software on remote physical computers. The use of the Amazon Web Service cloud environment as a common tool for working with data and the ability to use ready-made extensions is proposed. Also, this cloud technology simplifies the procedure of public and secure access to the collected information for further analysis.

Originality/value: Use of cloud environments and databases to monitor ammonia pipeline defects for correct resource assessment.

Keywords: Underground ammonia pipeline, Pump station, Thermal background, Corrosion currents, Data processing, Cloud computing

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Ammonia emissions are dangerous to human health and timely diagnosis of possible leaks is an important task of information technology. Metals are subject to corrosion under external and soil influences and load during transportation [1,2]. Continuous monitoring of changes in the places of damage to the coatings and timely repairs will help increase the longevity of the resource and avoid harmful emissions into the environment [3-6].

Metallic components of underground constructions have a certain service life, which is exhausted every year. The probability of detecting defects increases from year to year. Ammonia pipelines are a common way of transporting ammonia in the world. One of the largest in Eastern Europe is the Togliatti-Odessa ammonia pipeline. It has a number of properties that distinguish it from its use in comparison with other metallic structural components. There are certain requirements for the transportation of ammonia because ammonia is in a liquid state under a pressure of up to 35 atmospheres with a temperature of 4°C. In addition, 0.4% of water is added to prevent corrosion. Moreover, in places of the possible danger of leakage or damage or when approaching water bodies, the principle of "double pipe" is applied. It is then that the thickness of the pipe can be inhomogeneous and vary according to the surrounding operating conditions. Thus, early detection of the location of damage helps to avoid accidents and harmful emissions into the atmosphere or the earth's surface. Predicting phenomenon such as ammonia leakage from a pipeline is a rather complex process.

Pumping stations (PS) provide a relatively stable flow of ammonia within the underground steel pipe. It is necessary to take into account corrosion currents, the temperature distribution in the vicinity of the emergency, as well as temperature deviations during the day.

It is necessary to take into account the condition of the sections of the ammonia pipeline at a distance of up to 20 km from the pumping station. Such areas are areas of increased risk and corrosion damage due to the effects of temperature, mechanical loads, and soil moisture on the metal of the pipe in places of insulation damage.

The relevance of the relevant research is related to the control of corrosion defects (pitting) on the surface of the metal of the pipe in places of insulation damage and the corresponding effects of temperature, mechanical stress, and aggressive environment on corrosion processes. Therefore, it is necessary to diagnose corrosion defects and develop measures aimed at optimizing the modes of operation of the emergency in order to prevent stress-corrosion fatigue (SCF).

There are many known methods for monitoring ammonia pipelines, as well as the detection of corrosion defects on their surface [7]. Recent studies allow determining the location of depressurization of underground pipelines during the monitoring of oil and gas companies [8]. However, it is necessary to take into account the peculiarities of ammonia transportation. It is important to take into account heat pulses [9,10], which also occur in research.

Due to the fact that the service life of underground metallic components of structures (UMCS) is limited, there may be a loss of their load-bearing capacity. In other words, ammonia pipelines are subject to corrosion because they are located underground and in contact with the ground electrolyte. Therefore, the environment affects the durability and service life of UMCS.

In [7,11] the results of researches of diagnostic parameters which characterize corrosion processes in local defects on a metal surface are presented. However, issues related to the risks and quality criteria of the SCF remain unresolved. The reason for this may be the insufficient justification of surface effects related to the strength criteria.

All this gives grounds to claim that it is expedient to conduct a study to take into account the influence of periodic changes in ambient temperature (soil) on the corrosion process in the coating defect on the metal surface similarly to scientific articles [12].

In [13] a method of control of thermal changes in underground metallic structures is proposed. However, this information is not enough to detail the issues related to thermal changes in the vicinity of pumping stations. The reason for this may be the difficulties associated with the imperfection of the assessment of energy parameters, which are included in the criteria of strength and quality criteria [7,11]. To overcome this type of problem, it is advisable to take into account the migratory flows of the substance at the boundary between soil and metal [14].

It is important in this context to evaluate the effect of electrochemical overvoltage of the reaction of anodic dissolution of metal (steel) at the crack tip on the corrosion current density in the coating defect on the outer surface of the ammonia pipeline.

The development of a system for monitoring the condition of ammonia pipelines in places of potential breakthrough helps to prevent significant ammonia losses. An important process for determining the zones of environmental pollution is the reduction of excess pressure in the ammonia pipeline, as well as changing the height of the jet and the mass of ammonia coming out of the pipe. Relevant indicators make it possible to assess the level of air and ground surface pollution in the event of a leak in the ammonia pipeline.

A system that uses modern data processing methods has been developed to monitor defects. In recent years, the use of cloud technologies and computing for data processing has become particularly active [15]. These technologies allow you to quickly and securely deploy software for both public Internet access and private access with limited access.

The main element of the data processing system (DPS) is the use of a web service, which serves as software for processing requests from customers to the service itself. Typically, such systems (DPS) are directly related to databases and knowledge and act as an additional layer of system protection [16,17]. Data obtained from web services is transmitted for visual presentation of data on a web page that is deployed in a cloud environment. On this basis, a comprehensive model for monitoring surface defects and automation of the processes of their detection and calculation of technological modes using appropriate theoretical approaches are implemented.

2. Experimental procedures

Based on the data obtained from articles [8,9] for the test purpose, the test data were used for further processing and visualization of information in DPS. As a result of the analysis of articles [7,12] with the help of artificial neural networks (ANN) it is proposed to analyse the information obtained from the use of periodic thermal boundary ratios for the analysis of physicochemical processes at the boundary of metal and aggressive environment.

Devices for monitoring depressurization, which measure pressure, potentials, and corrosion currents are presented in the article [8]. It is proposed to use the RS-232 information transfer interface to connect and transfer data from the measuring devices to the microcomputer. In turn, the microcomputer can send the results in JavaScript Object Notation (JSON) format to a web service, where they are processed and displayed on graphs on a web page. A Raspberry PI microcomputer or an Arduino microcontroller can be used to group data into the appropriate JSON format and extract all information from external devices [18].

The client-server architecture allows many clients to work with the service simultaneously. This procedure has become especially popular for interaction with web pages [19]. In the developed system the central element is considered to be a web service. The architectural service was represented by the architectural style Representational state transfer (REST), which best interacts with the JSON format. The appropriate data exchange occurs on the base of the Internet protocol Hypertext Transfer Protocol (HTTP) [16].

A non-relational Elasticsearch database was used to store the data. This database is based on the Lucene library and is considered to be a search engine. In addition, there are many ways to search for information such as full-text, partial search with filters, and so on. All DPS data are stored in JSON format and are divided into separate indices with a certain number of shards and replicas.

Visualization of results is implemented on the basis of web technologies [20] to present data in graphical form. In addition, ready-made libraries such as Bootstrap and jQuery were used for simplified and modern web design. Modern technologies for web applications are multi-browsers, i.e. the information is displayed in the same way in most cases by today's popular browsers, such as Google Chrome, Firefox, Edge, etc.

Among the most popular cloud environments, there are Amazon Web Service, Microsoft Azure, and Google Cloud Platform. Each of these environments has similar platforms for working with the database, saving files, recovering data and configuring the most remote server computers. Amazon Web Service was chosen as the system for deploying information due to the best system properties (DPS) and relevant aspects of configuration [21].

3. Results and discussion

To study the effect of thermal processes on corrosion effects in the vicinity of pumping stations, it is necessary to estimate heat losses on the surface of underground structural components using models and techniques that take into account changes in heat transfer conditions between the pipe and the environment [22]. In this context, we take into account the thermal resistance of the soil in the same way as in [23]:

$$R_S = ln\{(d/r_{op}) + [(d/r_{op})^2 - 1]^{\frac{1}{2}}\}/(2\pi k_S), (d/r_{op} > 2),$$
$$R_S = ln(2d/r_{op})/(2\pi k_S), (d/r_{op} > 4), \tag{1}$$

where R_S – thermal resistance of soil, (m·K)/W; d – the depth of occurrence to the centreline of the pipe, m; r_{op} – the outer radius of the pipe, m; k_S – the thermal conductivity of soil, W/(m·K).

The results of assessment of the thermal resistance of the soil using formula (1) are presented in Table 1. The thermal conductivity of the soil k_S is inversely proportional to R_S, because the coefficient between them is dimensionless.

Table 1.
Thermal resistance of soil R_S depending on the distance L

R_S, (m·K)/W	1	1.5	2	2.5	3
d, m	1.5	1.6	1.7	1.8	1.9
r_{op}, m	0.5	0.7	1.0	1.3	1.5

The thermal resistance of the coating is written in the same way as in [24]:

$$R_P = ln(r_Z/r_{op})/(2\pi k_P), \tag{2}$$

where R_P – the thermal resistance of the coating on the pipe surface, (m·K)/W; k_P – the thermal conductivity of the coating, W/(m·K); r_Z – the outer radius of the coating, m.

The results of assessment of the thermal resistance of the coating on the pipe surface using formula (2) are presented in Table 2.

Table 2.
The thermal resistance of the coating on the pipe surface R_S depending on the distance L

R_P	3.5	4.5	5	5.5	6
r_Z - r_{op}, mm	0.5	1.6	1.7	1.8	1.9

Where: r_Z - r_{op} is the coating thickness (the thickness of the primer is 0.02… 0.03 mm, and the thickness of the mastic coating is 7.5 mm).

If, for example, the temperature of the environment (soil) in the natural state is T_{GR}=20°C (±2°C) and the temperature of the ammonia in the tube is $T(z)$= 4°C, then the environment is characterized by such a temperature pressure [24].

$$\Delta T = T(Z) - T_{GR} = 10 \ldots 20°C,$$
$$\Delta T = T_{\mathrm{GR}} - T(Z) \approx 14 \ldots 18°C \tag{3}$$

The specified conditions (1), (2) and pressure (3) correspond to the results of the experiment according to the method [11,14] regarding the corrosion current density J which are shown in Table 3.

Table 3.
Corrosion current density J depending on the distance L to PS

L, km	0	4	8	12	16	20
J, A/m^2	0.18	0.25	0.28	0.33	0.35	0.28
J_L=J/J_0	1.62	2.23	2.54	2.92	3.15	2.46

In the Table 3 corrosion current density is equal to J_0=0.112 A/m^2.

Instead of determining the errors with respect to the data in Table 3, it is expedient to estimate the uncertainty of physical processes of the system "PS-SAP (surface of ammonia pipeline)" in the soil environment. General information on the uncertainty of experimental studies is presented, in particular, in [25]. For a more detailed assessment of the uncertainty Δ_V of data such as J_L, J_V in Table 3 we use formulas (1-3), methods of articles [24,25], as well as an analytical relationship similar to the expression given in the article [25]:

$$U_Z = U(exp) \cdot U(m) \cdot U(r) \cdot U(repl) \cdot U(qual), \tag{4}$$

$$\Delta_V = \Delta_E \cdot \Delta_M \cdot \Delta_R \cdot \Delta_D \cdot \Delta_Q, \tag{5}$$

where: Δ_E – uncertainty associated with experiment errors; Δ_M – methodological uncertainty; Δ_R – uncertainty of result; Δ_D – uncertainty in duplication; Δ_Q – uncertainty of methods for assessing the quality of the system "PS – SAP" [14].

The results of assessment of the uncertainty of experimental data using formulas (4) and (5) are presented in Table 4. It was found that uncertainties are similar to errors. Formulas (4) and (5) are related to the experiment. Uncertainties are similar to errors. Errors U_i are deviations from the exact values of the parameters, whereas uncertainties Δ_i are deviations from the average values of the parameters.

Table 4.
Assessment of the absolute uncertainty U_i depending on the relative uncertainty Δ_i

U_i	2	4	6	8	10
Δ_i	2	4	6	8	10

In this case, based on a computational experiment, it was found that the uncertainty for the data of Table 3 taking into account the relations (1)-(2) and the methods of articles [14,26] takes the value Δ_V=0.08…0.11.

In Figure 1, a general model of the system for monitoring and visualization of data, in particular heat pulses and pressure, is presented. The schematic image contains a set of plots for research with the corresponding input data meters. The collected data are then transferred to a microcomputer, where they are converted to the desired JSON format and sent to a web service for further processing and visualization.

In Figure 2 the view of the record in the Elasticsearch database and the response from the web service is shown. HTTP data puncture is used, which involves the use of HTTP methods such as GET, POST, PUT, DELETE, etc. Data exchange takes place using HTTP status codes. Upon successful retrieval of data, the web service must display the data on the web page and send a status code in the response header 200, if the page is not found – 404, and if there is a problem with the server – 500. According to such codes, the client without opening the program can immediately see the error on the client-side or on the server-side and requires the intervention of developers.

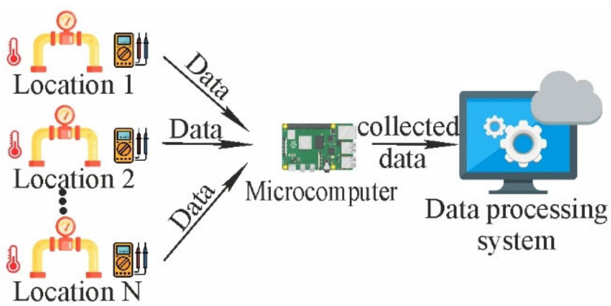

Fig. 1. Block diagram of the system for the selection of information from the ammonia pipeline

Fig. 2. Results of entries (a) in the database and (b) responses from the web service from Microsoft Edge Web Browser

The JSON responses displayed on the webpage have taken a form that is readable and editable. The essence of this approach is to use "key-value". Each of the investigated sections of the ammonia pipeline is placed in blocks with a description of the parameters and their values. That is why the values and parameters can be easily found when analysing, searching, or changing data (DPS).

In addition, in Figure 2a, you can see the web page address where the non-relational Elasticsearch database client is running. An index has been created in the site address, which contains all the collected and processed data for the studied area of underground metallic structural elements. In Figure 2b, the response from the web service used by the web application to visualize the data is shown.

In this case, the best data visualization suggests the use of graphs. The following representations may be among the most popular: line, pie, and bar charts. Most often, in practice, a representation in the form of a linear graph is used, where there is a dependence of certain values on both axes. In a pie chart, the value is visually seen from the length of the diagram.

According to the graphical representation in Figure 3 we see the temperature range and the number of accidents D_{A*} for the underground gas pipeline per 1 km, which are obtained similarly to the article [9]. The blue curve of the line diagram, the values of which start from 3 and decrease to 1, shows the dependence of the change in the temperature range T/T_0. The grey curve, which starts at 1.1 and ends at 1.23, shows the dependence of the change in the density of accidents D_{A*}.

Fig. 3. Presentation of accident data during depressurization and thermal pulses and in a line graph and pie chart, respectively

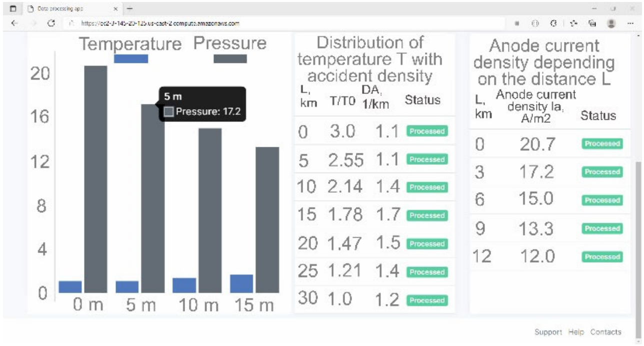

Fig. 4. Comparison of data on accidents during depressurization under the influence of thermal pulses in a bar chart and tabular form

Besides, in Figure 3, the pie chart shows the dependence of the number of probable D_A accidents associated with depressurization on the distance to the pumping station. This confirms the information about the anode current density, which decreases in the same way as in [8]. The number of probable D_A accidents associated with depressurization is proportional to the probability of P_A risk situations.

When you hover the cursor over the corresponding element in the graphic part of the page, the values temperature and pressure are displayed and allow you to clearly see the difference between the values of the corresponding parameters. In the case of researching and processing large amounts of data, such visualization will significantly reduce the time to analyse the original data.

In Figure 4 we see a representation in the form of a bar chart of two graphs that can be compared. Because it is important in ammonia pipelines that the temperature is within certain limits for safe transportation, these two processes (heating and the effect of internal pressure on depressurization) must be considered simultaneously. The first 20 kilometres should be considered for data analysis. The corresponding results are presented in the table on the web page. Thus, we can say that the number of D_A accidents associated with thermal pulses for UMCS per 1 km increases with increasing a distance similarly as in [9] and the anode current density decreases. This affects the internal pressure in the pipe with ammonia as well as on the depressurization. The change in numerical values of temperature is shown in blue in the bar chart, and the change in pressure is shown in grey.

The influence of heat pulses and internal pressure on the corrosion current density *J*, the number of probable D_A accidents, and the probability of ammonia pipe destruction P_A is shown. This information is important for predicting the operating conditions of the ammonia pipeline.

The possibility of using a cloud environment and a system with test data has been demonstrated [8,9]. The components of the system (DPS) can be changed. In particular, you can replace the test data, as the format is expected to be unchanged. The system (DPS) can be extended and perform additional calculations. Due to the use of cloud technologies, the system is easily scalable (DPS). This means that you need to increase server performance (CPU, storage) or optimize the system through additional settings. Queries can be made to the database using the ready-made Application Programming Interface (API). HTTP data transfer protocol is one of the most popular in browsers and web services. Communication between all components of the system requires a constant Internet connection.

Elasticsearch is used for large amounts of data and works best when configured correctly, as non-relational databases work with unstructured data. That is why, when monitoring data on many sections of the pipe, it will be easy to identify them by dividing the data into indices according to the section. The results regarding the corrosion current density and the probability of risky situations are presented in different data representations, namely, in the form of a line graph, a pie chart, and a bar chart. The system (DPS) can adapt to work with a large amount of input data.

4. Conclusions

1. A method of taking into account heat pulses and internal pressure for the study of risky situations on the outer surface of the underground metallic ammonia pipeline at a distance from the pumping station in the range L = 0…20 km.
2. The need to take into account the excess pressure in the ammonia pipeline and other important parameters related to ammonia and pipe metal is shown.

3. The relationship between the influence of thermal pulses on corrosion currents, which are related to the probability of risky situations, and the density of accidents in the vicinity of the pumping station of the ammonia pipeline has been found.
4. The analysis of diagnostic signs on the outer surface of the underground metallic ammonia pipeline is carried out taking into account temperature changes and corrosion currents.
5. The parameters and relations of the mathematical model for the description of thermal processes and mechanical loading in the vicinity of pumping stations are offered.
6. The system (DPS) is designed to analyse large data sets from multiple locations and automatically calculate intermediate results, simplify routine work for researchers, and display in real-time the situation that may arise in the future.

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