DOI: 10.31471/2311-1399-2019-1(11)-30-33

Factors of effect on the corrosion destruction of metal of underground pipelines

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Received: 06.06.2019 Accepted: 12.06.2019

Abstract

A set of studies was conducted to determine the main factors influencing the corrosion destruction of metal in underground pipelines in two studied sections of the Pasichna-Tysmenitsa gaspipeline, covering definitions of active acidity, mass fraction of moisture, the presence of sulfate ions, and metal weight loss determined by the gravimetric method. It has been established that the pipeline in the studied sections of the route is laid in a soil of uniform acidity, which is low in pH acidic, which indicates corrosiveness of the soil in relation to steel. High soil moisture from the bottom of the pipeline in two sections of the route 18.21 and 19.73 %, respectively, contributed to increased corrosion damage of the metal. Corrosion of the studied soils was carried out on the basis of certain metal weight loss. It was established that the soils on the studied sections of the route, the distance between which was about 1000 m, relate to soils with a high and normal degree of corrosivity. High corrosion activity is characteristic of the soil along the lower generatrix of the pipeline, which leads to an increase in the corrosion rate of the metal of underground pipelines in this zone. The intensification of corrosion processes in the soil adjacent to the pipeline, with an increase in metal exposure time in soil, has been established. The presence of sulfate ions in soil water extracts leads to the development of biocorrosion with the participation of sulfate-reducing bacteria, which indicated the formation of biogenic hydrogensulfide.

Keywords: *environmental hazard, insulation coating, pipeline, soil corrosiveness, sulfate-reducing bacteria.*

Introduction

The problem of improving the operational reliability and efficiency of the pipeline transport of Ukraine in the conditions of intensive development of energy markets is extremely important for ensuring the energy security of our country. In the course of operation of the main pipelines, one of the most serious problems is risk of accidents (unforeseen failure of the linear part of the pipeline), which is accompanied by catastrophic impact on the environment due to contamination of soil, air and water basins with the products of energy carriers transportation.

The causes of pipeline failures are covered in [1–6]. More than 80 % of all failures were due to corrosion of metal pipes [4]. This dramatically increases the environmental risk of further exploitation of such metal structures and keeps current the problem of estimating their residual resource. In the process of long-term exploitation of underground pipelines laid in soils of different corrosion activity, environmental hazards are formed in some regions of Ukraine due to the destruction of pipelines as a result of exceeding the normative resource of their exploitation, degradation of the insulation coating, due to soil and microbial corrosion. The main factors influencing the corrosion destruction of metal pipelines in the underground environment are: the chemical nature of soils, their humidity, acidity, resistivity, redox potential, the presence of associations of soil microorganisms etc. The biological factor plays a significant role in damaging the pipes in the underground environment. Soil microorganisms, such as sulfate-reducing bacteria are particularly corrosive, they are involved in the most dangerous variety of corrosion processes, namely, in local corrosion destructions: pitting, ulcerative corrosion under insulation [1]. As a result of the influence of these factors, the degradation of the insulating coating carries out, which leads to its further cracking and peeling, which results in the intensification of corrosion of the pipe metal under the impact of the soil electrolyte (Fig. 1).

Figure 1 – Corrosion damage to metal pipe

The annual amount of officially accounted losses from bio-corrosion damage of metal in industrially developed countries, where corrosion protection is

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carried out at the proper level, is from 2 to 3 % of the cost of production of materials.

Despite the fact that research has continued to develop rapidly in the field of corrosion protection by various scientists, an analysis of previous works has shown that insufficient attention has been paid to studies related to the modification of insulating coatings to give them qualitatively new properties, in particular, bio-resistance. In addition to quality protective insulation, it is important to take into account the factors of influence that determine the corrosive activity of soils in which underground pipelines are laid to ensure their reliable operation. It is impossible to get rid of the risk of corrosion damage by increasing the allowance of the thickness of the pipe wall to compensate for metal losses, requires the adoption of special measures to eliminate the causes of corrosion localization, an important place among which is the control of the factor of biocorrosion.

In view of the abovementioned, the purpose of this paper was to conduct a set of studies to determine the main factors influencing the corrosion destruction of metal underground pipelines to determine the degree of corrosion activity of the soil. The objects of study were soil samples from two sections of the Pasichna-Tysmenytsia gas pipeline (main gas pipeline), with distances of about 1000 m between them.

Research results

Investigation of corrosion activity of soils comprised a complex of factors, characterizing the corrosion, such as the acidity of the soil, mass fraction of humidity ω_{H_2O}, presence of sulfate ions, as well as the loss of the mass of the metal, determined by the gravimetric method. Soil sampling was carried out in accordance with the methodology of the official DSTU 3291–95 [7]. The appearance of the first traces of penetration corrosion is very characteristic in terms of soil corrosive activity assessment. It is undoubtful that such an assessment is approximate, because the process of corrosion of steel pipelines depends not only on soil conditions, but also on steel grades, as well as quality and material of welded joints, thickness of pipelines walls, protective coating quality and pipeline operation conditions. Nowadays, there is a significant number of field and laboratory methods for identifying corrosion activity of soils [2, 8, 9]. Considering a wide range of reasons for corrosion of metal in soil, none of these methods separately can give an accurate picture of the assessed corrosion activity of soils. A correct assessment of the corrosive activity of the soil can be done only after investigation of soils, using different methods and by matching the results of these investigations, considering local geographical and climate conditions. Samples of soil from the sites under investigation differed from each other in terms of particle size distribution (Table 1).

Soil samples were dried in an oven at 95–98 °C, ground in a porcelain mortar, sieved through metal sieves, and soil fractions (≤ 2 mm) were selected for further investigation. As one of the important factors characterizing the corrosive activity of the soil is the acidity, it was important to monitor the change in the acidity of the soil selected from the top, bottom and middle part of the pipeline. Soil acidity is caused by the presence of hydrogen ions, the concentration of which is expressed by pH. The pH value in the soil varies depending on the general mineralization of groundwater and the presence of carbonate and mineral acids, acidic and basic salts [9]. The actual acidity is caused by hydrogen ions present in the soil electrolyte. Its value is assessed by the results of the analysis of water extract from the soil. Actual acidity characterizes the acidity of the soil at the time of its determination. The actual acidity of the selected soil samples was determined using the universal indicator and pH meter of the pH 150MI brand according to the method [6] (Table 2).

Table 1 – Particle size distribution of soil from sites under investigation

Section	Sampling place	Particle size distribution
I	*sample 1 (bottom)*	Black and gray dense clay with high iron content
	sample 2 (top)	Sandy medium-grained black and gray soil with remnants of plant roots
	sample 3 (middle)	Gray and brown loam with the inclusion of rubble
II	*sample 1 (bottom)*	Yellow and grey dense clay
	sample 2 (top)	Loam with layers of sand
	sample 3 (middle)	Loam with brown layers of iron and manganese oxides

Table 2 – Results of determination of pH of water extracts of soil samples, qualitative content of SO_4^{2-} ions in ground waters and mass fraction of moisture in soil samples of the Pasichna–Tysmenytsia main gas pipeline

Section	Sample	pH	SO_4^{2-}	ω_{H_2O} , %
I	1	5.25	++	18.21
	2	5.57	+ –	4.74
	3	5.51	+	10.48
II	1	5.07	+++	19.73
	2	5.72	+	5.62
	3	5.44	++	12.55

The analysis of the obtained results showed that the pipeline on the investigated sections of the route is laid in acidic soil, which by its pH value is weakly acidic, which indicates the corrosive activity of the soil towards steel. To exclude the possibility of corrosion enhancement by the influence of sulfate ions (SO_4^{2-}), water extracts of soils were analyzed for presence of SO_4^{2-} by qualitative reaction with an aqueous solution of barium chloride (Table 2). White precipitation indicated the presence of SO_4^{2-} ions in groundwater. The results of the qualitative analysis showed that groundwater from below the pipeline is the richest in sulfate ions, the content of which decreases towards the top of the pipeline. The content of sulfate ions indicates the presence of sulfate metals in the soil. Another factor for correct assessment of soil corrosion activity is soil humidity. Determination of soil humidity by gravimetric method showed (Table 2) that the most humid soil is located below the pipeline, which contributes to the enhancement of corrosion processes.

To make a complete conclusion on the corrosive activity of soils, the weight loss of metal calculated by gravimetric method was also analyzed. For this purpose, the metal rods, previously weighed on an analytical scales VLF-200, were placed in the steel cylinders that served as the cathode. A clay fraction (clay selected from above, below, in the middle of the pipeline) was poured into each of the cylinders. The prepared cylinders were left for a specified time under the impact of electric current 6V (Fig. 2).

Figure 2 – Unit, used to define corrosive activity of soils

At the end of the exposure, the metal rods were removed from the soil, subjected to mechanical and chemical treatment to remove corrosion products from their surface. It should be noted that as a result of washing the rods with a solution of hydrochloric acid, a sharp odor of the isolated hydrogen sulfide formed as a result of the destruction of the sulfide ferrum was felt. The formation of a biogenic sulfide ferrum testified to the development of microbiological processes in the soil electrolyte, which led to the intensification of corrosion destruction of the metal. Figure 3 presents the dynamics of metal mass loss in the first section of the studied route.

The analysis of the experimental results of the loss of mass of the metal showed that soil located below the pipeline along the so-called lower generating pipeline, characterized by the predominant content of sulfate ions, is the most corrosive. This zone directly contacts the metal surface of the pipeline, the so-called "ferrosphere" [10]. Due to the corrosion damages of the pipeline in the soil, which occur in this zone, there is an accumulation of bivalent iron ions and a decrease of redox potential, which intensifies the vital activity of sulfate-reducing bacteria, which stimulate corrosion processes, the intensity of which is maximum in dense corrosion-dangerous soils. With the increase of exposure time to 72 hours, corrosion destruction of the metal in the area adjacent to the bottom of the pipeline increases. According to the data obtained, the soil below the pipeline by the weight loss of the metal has a high corrosion activity. While the soil selected in the middle and top of the pipeline refers to soils with normal corrosion activity. A somewhat different situation was observed in the loss of metal mass, determined on the second investigated section of the route of the Pasichna-Tysmenytsia main gas pipeline (Fig. 4).

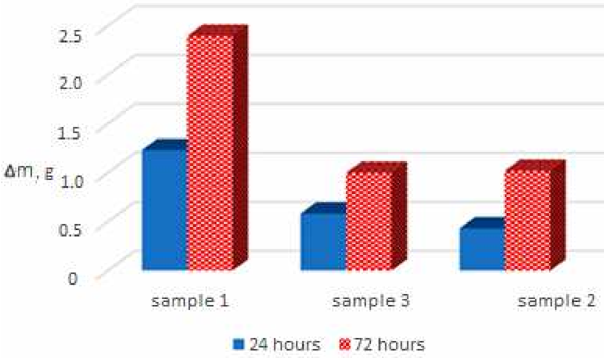

Figure 3 – The loss of metal mass on the first section of the Pasichna–Tysmenytsia main gas pipeline

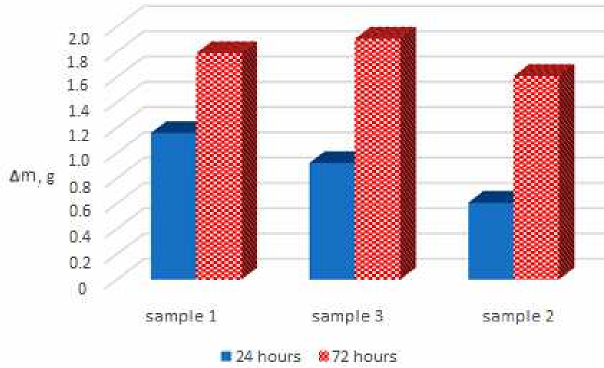

Figure 4 – The loss of metal mass on the second section of the Pasichna–Tysmenytsia main gas pipeline

The results of the studies showed that for 24 hours of the experiment the most evident corrosion damage is also characteristic for the soil from the bottom of the pipeline. With increasing metal exposure time in soils up to 72 hours, the intensification of corrosion damage was observed, which was accompanied by an increase in metal loss for all soil samples. However, there was a slight difference in the weight loss of the metal (up to 10%) in the soil selected from below and in the middle of the pipeline, which is characterized by high corrosion activity. It should be noted that at the end of the exposure, all the metal rods were covered with black precipitate of ferrous sulfide, upon removal of which a strong odor of hydrogen sulfide was noticeable. The formation of biogenic hydrogen sulfide is associated with the restoration of microorganisms by sulfate ions to sulfide ions, which indicates the development of microbiological corrosion destruction with the involvement of sulfate-reducing bacteria.

ISSN 2311—1399. Journal of Hydrocarbon Power Engineering. 2019, Vol. 6, Issue 1

Conclusions

The influence of the main factors on the corrosion destruction of metal at two sections of the Pasichna-Tysmenytsia main gas pipeline was evaluated. As a result of a comprehensive soil survey, it was found that soil at the bottom of the pipeline has high soil corrosion activity. The soil located in the middle and top of the pipeline is characterized by normal corrosion activity.

It has been established that with the increase of the time of metal exposure in the soil corrosion processes are intensified and the greatest losses of the anodic dissolution of the metal are characteristic for the zone along the lower generating line of the pipeline. The presence of sulphate ions in the water extracts of soil in the investigated sections of the Pasichna–Tysmenytsia main gas pipeline causes the development of microbiological corrosion with the participation of sulfate-reducing bacteria.

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УДК 622.4.076:620.197.6

Оцінка корозійного руйнування металу підземних трубопроводів

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Досліджено вплив основних факторів на корозійне руйнування металу підземних трубопроводів на двох ділянках траси магістрального газопроводу Пасічна–Тисмениця, а саме оцінку активної кислотності, масової частки вологи, наявності сульфат-йонів, а також втрату маси металу. З’ясовано, що трубопровід на досліджених ділянках траси прокладено в однорідному за кислотністю ґрунті, який за величиною pH відноситься до слабокислого і вказує на корозійну активність ґрунту по відношенню до сталі. Висока вологість ґрунту знизу трубопроводу на двох ділянках траси (18.21 та 19.73 %) сприяла посиленню корозійному руйнуванню металу. Встановлено, що ґрунти на ділянках траси, віддаль між якими складала близько 1000 м, відносяться до ґрунтів з високим та нормальним ступенем корозійної активності. Висока корозійна активність характерна для ґрунту по нижній твірній трубопроводу, що призводить до збільшення швидкості корозії металу підземних трубопроводів в цій зоні. Зі збільшенням часу експозиції металу в ґрунті спостерігається інтенсифікація корозійних процесів в ґрунті, що прилягає знизу до трубопроводу, Наявність сульфат-йонів у водних витяжках ґрунту спричиняє розвиток біокорозії з участю сульфатвідновлювальних бактерій, що свідчило про утворення біогенного сірководню.

Ключові слова: *екологічна безпека, ізоляційне покриття, корозійна активність ґрунту, сульфатвідновлювальні бактерії, трубопровід.*