Bituminous Insulations Durability of Underground Metallic Pipelines
I Field investigations

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The corrosion state of an underground metallic pipeline of Ø161 mm and 565 m length was assessed by specific electrical and electrochemical measurements. The investigated pipe, buried in 1997, was protected against corrosion by successive layers of bituminous material with a total thickness of 1 to 1.2 mm. The pipeline crosses three electrified railway lines (50 Hz - 28 kV), and then its route is approximately parallel to these lines; thus, the induced AC voltages between line and ground were calculated obtaining values between 4.05 and 7.1 V_{rms}, in good agreement with the values measured in the accessible points. The measurements regarding the insulation capacity against corrosion of the bituminous insulation, performed at one month and after 19 years of burial, showed an increase of the average cathode current density needed for obtaining the protection potential in the range –1.00 ÷ –1.28 $V_{Cu/CuSO4}$ of approx. three times (from 6.65 up to 19.96 $\mu A/m^2$), in good agreement with the evolution of the insulation resistance measured between the steel pipe (having a contact area with the ground of 270.5 m^2) and a ground socket of 4 Ω, which decreased from 995 to 315 kΩ. Following the analysis and processing of the field collected data, it is considered that, by implementing a cheap cathodic protection system (without cathodic current power supply), based on the rectification of the AC induced voltage, the safe operation period of the investigated pipeline may be extended by at least 50 years.

Keywords: metallic pipeline, bituminous insulation, corrosion, AC stray currents, induced AC voltage

In terms of sustainable development, the issue of ensuring safe urban utilities, including natural gas, is of particular importance. The safe operation of underground urban utilities distribution networks (including those with high-risk operation, such as natural gas distribution) is determined by the durability (in specific operating conditions) of the materials used in the distribution network construction.

In the urban underground agglomerations coexist a series of distribution networks utilities, made of various materials. These networks are exposed to a series of stress factors, which lead to the degradation of the materials used in the network construction [1]. Under the action of aggressive factors of soil (salinity, humidity, oxygen, microorganisms [2-7], etc.), the metallic components of underground networks are exposed to electrochemical corrosion and microbiological degradation, unless adequate safety measures are taken. The organic materials, including polymers, used either to achieve tubular material (pipe) for metallic pipes insulation [8, 9], or to achieve power cables [10-13], under the influence of environmental factors, are exposed to aging by a complex of thermal and oxidation processes, microbiological deterioration etc.

In electrolytic environments polluted by organic products [14] and in those disturbed by AC stray currents (due to the disruptive 50Hz electric field that alter the biochemical processes of metabolism [15,16]), the growth and multiplication of mould intensifies [14, 18], leading to the acceleration of corrosion [19] and enhancing the microbiological deterioration of polymeric materials.

Underground metallic structures made of metals of different qualities and buried in a heterogeneous electrolytic medium (soil), electrically interfere with each other, which leads to the acceleration of corrosion processes. On the other hand, the underground metallic pipelines are exposed to accelerated corrosion due to both D.C. stray currents (coming from inland D.C. powered tram and / or subway) and to A.C. stray currents (coming from the transmission and distribution of electricity) [20-28].

In order to prevent faults due to the degradation by corrosion of underground metallic pipelines [29], numerous research [8,9,25, 26, 30] are performed regarding the development and characterization of new protection materials and methods.

Thus, it results that the issue of safety operation of underground networks is complex and multidisciplinary (materials science, chemistry and electrochemistry, electrical engineering etc.) and has significant applications.

For the primary insulation of steel pipelines, the bituminous insulations with different reinforcements (paper, PVC tape, fibreglass, etc.) have been practiced for over 100 years. Many of these pipelines are still in use.

Prevention of faults and durability and increased safety operation, may be ensured only by implementing appropriate protection methods [20, 31, 32] (technical effective and acceptable in economic terms) and by performing studies of preventive intelligent diagnosis - by sound estimation of the remaining life time [8, 9, 12] and predicting / scheduling the repairs and / or replacement, as required. Without these measures, pipelines degradation may lead to serious accidents with high material, social (often with multiple casualties [33, 34]) and ecological costs.

Given the above considerations, the aim of this paper is to assess the corrosion state of a metallic pipeline with bituminous insulation, exposed to the concerted action of AC stray currents and soil aggressive factors for 19 years.

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Experimental part

Procedure

The medium pressure of the underground gas pipeline of Ø161 mm and 565 m length was investigated; the pipe is buried on Libertatii Street, in Aninoasa city, Hunedoara County and has a total buried area of 270.5m^2. The sketch of the site and the pipe framing in the area is shown in figure 1. Figure 2 shows representative images regarding the deployment and achievement of the investigated pipeline.

The steel pipe with reinforced insulation (three layers of bitumen) was buried in April 1997. The pipeline starts from the control metering station (SRM=CMS), being connected by an electro-insulating flange, **D**. It is buried near the roadway, on Libertatii Street (here having a 10 m apparent section **B-C**) until the level crossing to three electrified lines of railway (with a separating valve **A** for under-crossing the railway track). To 60 m from the pit where the separating valve is mounted, the metallic line is connected (underground) to a high-pressure polyethylene pipe [35].

To assess the quality of the bituminous insulation after 19 years and one month since the pipeline was buried, the following parameters have been measured:

- insulation resistance between the investigated pipeline and a ground socket of 4 Ω resistance with a FLUKE 1550 B giga-ohmmeter;
- the electrochemical potential (open circuit potential) pipeline/ground by a PHILIPS PM2718 millimetre and a $Cu/CuSO_4$ reference electrode;
- currents that ensure the cathodes protection, namely the pipeline/ground potential are between –1 $V_{Cu/CuSO4}$ and –1.28 $V_{Cu/CuSO4}$ on the whole section of investigated pipeline (provisional cathodic protection method) by a DC power supply, two PHILIPS PM2718 millimetres and a $Cu/CuSO_4$ reference electrode; the current injection was made by the flange connecting the pipe to CMS (D - fig. 3) unto the grounding lightning socket from CMS and the pipeline / soil potential were measured (from 10 to 10 m) with the help of the $Cu/CuSO_4$ reference electrode, by moving it along the pipe.

Result and discussions

To assess the disturbances of the metal/ground interface due to induced AC voltage, having implications both on steel corrosion process [19-28] and on mould growth on the bituminous insulation's surface [15-18], the distribution of 50Hz voltages along the investigated pipeline was determined by numerical interpolation [23, 24]. Voltage distribution modelling along the pipeline and a numerical calculation of the induced AC voltage were achieved on the basis of a simplified draft of the investigated pipe site (fig. 3) to the main disturbance source - a contact wires of electrified railway - 28 kV/50Hz (fig. 1 and 2).

The comparison of the results obtained by modelling and calculus with the onsite experimental ones is shown in figure 4.

The analysis of figure 4 reveals a good agreement between the calculated and measured values (with a maximum deviation of 4.88% in D). Also, the calculated minimum values were found on the railway under-crossing section, which may be explained by the shielding/screening effect of the protective tube. In addition, relatively small values resulted both from calculus and measurements in point D, which is located at the maximum distance from the disturbance source.

The results of the electrochemical potential measurements, E_{corr}, and of pipeline/soil insulation resistance, R_i, are summarized in table 1.

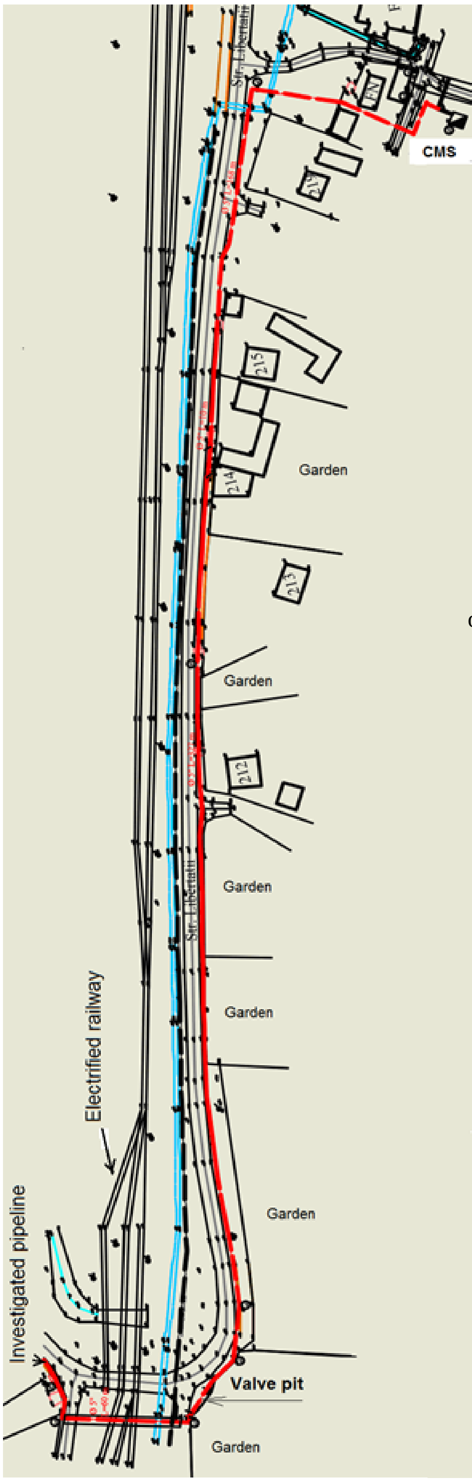

Fig.1. The layout of the investigated pipeline [35]

Fig.2. Representative images of the investigated pipeline: B-C – apparent section; D – the pipeline's end to the CMS connection

The analysis of the values presented in table 1 shows that after 19 years since the burial the overall resistance of the pipeline under investigation decreased approximately 3 times, from 995 kΩ (approx. 270 MΩ /m^2) to 315 kΩ (approx. 85.5 MΩ /m^2), respectively, which explains the

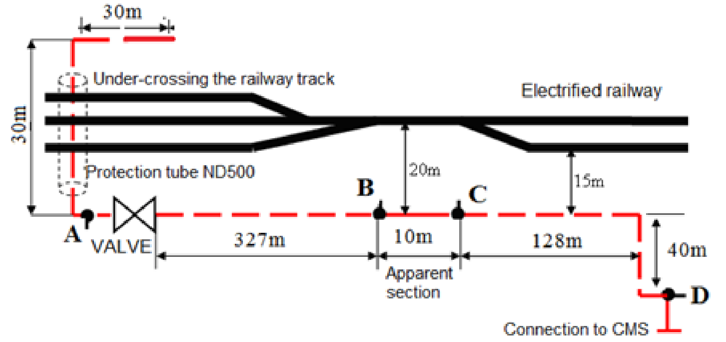

Fig. 3. Simplified draft for the numeric calculus of the AC voltage induced in the pipeline

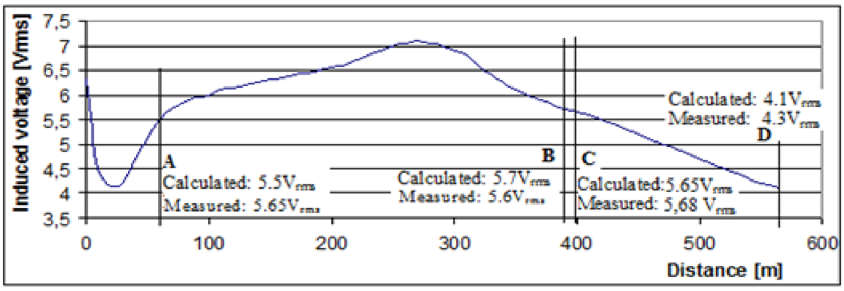

Fig. 4. AC voltage along the investigated pipeline - calculated distribution and measured values (in A, B, C and D locations)

Table 1

RESULTS OF THE MEASUREMENTS REGARDING THE ELECTROCHEMICAL POTENTIAL AND PIPELINE/SOIL INSULATION RESISTANCE

Measurement point	E_{corr} [$V_{Cu/CuSO4}$]		R_i* [kΩ]	
	May, 1997	March, 2016	May, 1997	March, 2016
A	– 0.401	–0.279	995	315
B	– 0.422	–0.281		
C	– 0.423	– 0.295		
D	–0.432	–0.360		

*- *values measured on the investigated section, with a total buried area of 270.5m²*

movement towards more electropositive values E_{corr} (leading to a increase in the corrosion rate).

By comparing the measured values in figure 4 with the time evolution of E_{corr}, one may see that the increase of the induced AC voltage leads to an acceleration of steel corrosion rate acceleration; this finding is in good agreement with some theoretical studies [21-23] and also with the results of some laboratory experimental research [19, 36, 37].

The results of the measurements regarding the cathode current density, J_k, necessary to achieve a total protection against corrosion of the investigated (potential E_k between –1 $V_{Cu/CuSO4}$ and –1.28 $V_{Cu/CuSO4}$), made by current injection in point D [35] (fig. 1 and 2), are summarized in table 2.

Figure 5 presents the distribution of the cathodic potential E_k along the pipeline, obtained using the currents specified in table 2.

By analyzing data in table 2 it results that after 19 years since the burial, the average cathodic current density J_k, required for a total protection of the pipeline against corrosion, increased approx. 3 times, i.e. from 6.65μA/m² to 19.96μA/m². This increase of J_k is due to the quality degradation (ageing) of the insulating bituminous layers, R_i, which, according to table 1, decreased also approximately 3 times in the same period.

Analyzing the potential distributions E_k, presented comparatively in Figure 5, immediately and after 19 years of burial, shows that, at the injected J_k currents, the measured potential E_k are systematically electropositive (although it falls within the potential protection area) for the pipeline with aged insulation than for the pipe with new insulation (immediately after burial). It is also found that the E_k distribution on the investigated pipeline, immediately after the burial is approximately linear, in contrast to that obtained after 19 years since the burial, for which the distribution obtained follows a function similar to the one of the calculated induced AC voltage distribution (fig. 4) - i.e. on the sections with higher induced AC voltage, the obtained E_k values are more electropositive. As at a global injected cathodic current I (for a set average J_k) the distribution of E_k values is determined by the distance between the measuring point and the injection anode and by the quality of bituminous insulation in the measuring point [9, 20, 27], this finding suggests that the aging degree of the bituminous insulation in the measurement points is correlated with the induced AC voltage. In these circumstances it can be concluded that the 50Hz induced AC voltage is a stress factor for the bituminous insulations, namely a higher AC voltage produces a more advanced aging of the bituminous insulation.

The bituminous insulation thickness for the investigated pipeline is approximately 1 cm; thus, from figure 4 it results that the electric stress (field) applied to the investigated bituminous material is between 4.1 and 7.1 V_{rms}/cm. For these values, the degradation of electrical insulation due to electrochemical treeing and/or polarization phenomena [12, 13, 38-42] is unlikely. In these circumstances, a plausible explanation for the aging of bituminous insulation in the ground could be the microbiological degradation under the action of filamentous fungi, whose hyphae penetrate the bitumen and retain moisture (reducing the volume resistivity); also, by metabolizing the carbon from bitumen, they produce organic acids (leading both to bituminous material structural changes and to soil aggressiveness increase in the vicinity of the pipeline). This

Table 2

EVOLUTION OF CATHODIC PROTECTION CURRENTS

Data	Total current I [A]	J_k [A/m²]	E_k [$V_{Cu/CuSO4}$]			
			A	B	C	D
16.05.1997	$1.8 \cdot 10^{-3}$	$6.65 \cdot 10^{-6}$	–1.225	–1.260	–1.262	–1.275
17.03.2016	$5.4 \cdot 10^{-3}$	$19.96 \cdot 10^{-6}$	–1.086	–1.121	–1.126	–1.278

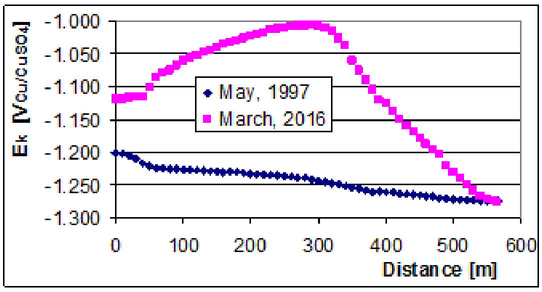

Fig. 5. Distribution of the cathodic potential E_k along the stabilized pipeline, following the injection of the currents specified in table 2.

explanation is supported both by the laboratory studies showing that the development and reproduction of filamentous fungi is strongly stimulated by the 5-10 V/cm electric field at 50 Hz [17] and by the results of some long term investigations and case analysis regarding the degradation of external polymeric jackets of underground power cables (exposed at 50 Hz electric field during operation), which showed that filamentous moulds in the soil have a decisive role in the initiation of polymer degradation [10-12].

Given these considerations, samples were taken both from the bituminous material of the pipeline cable insulation and from the soil surrounding the pipe in order to carry out laboratory investigations on physicochemical and structural changes suffered by the bituminous material, to identify the microbiological species prevailing in soil and to assess the resistance of the bituminous material to the action of the identified species [43].

Considering these aspects, it results that the bituminous insulation of the pipeline, being exposed for 19 years to an appreciable electric stress (induced AC voltage between 4.1 and 7.1 Vrms), shows a corrosion state close to the acceptability limit: monotonous distribution of E_{corr} between –0.360 and –0.279 $V_{Cu/CuSO4}$; thus, as shown in figure 5, it results that no major local defects/damages occurred in the insulation. In these circumstances, it is considered that, by implementing a cheap original cathodic protection system based on the recovery of induced AC voltage [20], [35] (without cathodic current power supply), the pipeline safe operation period may be extended by at least 50 years.

Conclusions

The corrosion state of an underground metallic pipeline with bituminous insulation, exposed to an electric stress by induced AC voltage was determined by electrical and electrochemical measurements. The processing and interpretation of the experimental data acquired on field, after 19 years and one month after the pipe burial, and of the values calculated for induced AC voltage distribution led to the following conclusions:

- the calculated induced 50 Hz AC voltage values are in good agreement with the measured ones, the maximum deviation being of 4.88%;

- the induced 50Hz AC voltage represents an electric stress factor for the bituminous insulation – in areas with higher AC voltage values, the bituminous insulation shows an increased ageing degree;

- the insulating resistance and the anticorrosive protection fell approximately 3 times during the 19 years of burial, falling still within the safe operation acceptable limits at the pipeline investigation date.

Based on the presented results, it is considered that, by implementing a cheap original cathodic protection system based on induced AC voltage recovery (without cathodic current power supply), the safe operation period of the pipeline under investigation may be extended for at least 50 years.

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