Sustainable and Safe in Exploitation of Gas Networks. *Part 2.* Stress Factors of Metallic Pipelines

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Abstract

The stress factors that determine the durability and safety in the metallic pipelines exploitation from to gas networks have been analysed. Studies have shown that underground corrosion is a form of "cancer" of metallic pipelines but, with the current knowledge, which we have, this form can be 100 % preventable and treatable. This involves knowing the mechanisms of acting stressors, respectively implementation and tracking the methods and modern devices and performance protective. During metallic pipelines exploitation, isolated with organic protection layers, are exposed to a series of stresses — natural factors (chemical and microbiological environmental aggressiveness, solar radiation in the UV and IR spectra, lightning currents, lightning) and/or of anthropogenic origin (AC and DC stray currents, aggressive pollutants such as SO2, NOx, dust-overhead pipelines, solvents, hydrocarbons, petroleum products and/or fatty-underground pipelines). Under the simultaneous and synergistic action of stress factors, the insulation capacity of the protective layers deteriorates and increases the activity of micro and macro corrosion cells. In the global corrosion process, the microbiological stress produced by filamentous molds that degrade the organic insulation layers have a special contribution and by the metabolic products accelerate the corrosion processes. It is noted that microbiological activity, especially of filamentous molds, increases substantially in the case of pipeline disturbed by AC stray currents at power frequency and global corrosion is much accelerated (synergistic effect).

Keywords: gas networks, pipelines, corrosion, biocorrosion, stray currents, AC corrosion

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1. Introduction

Sustainability and operational safety of thoroughfare, distribution networks and natural gas utilization facilities is a complex issue with special economic, social and ecological implications.

The complexity of the problem arises from the diversity of stress factors acting on the metallic pipes of the natural gas networks.

Under the concerted and synergistic action of stress factors, the pipelines material ages and diminishes its functional characteristics.

Gas networks by their very nature are high-risk installations in operation. Decreasing the functional characteristics of materials used in gas networks achieve (pipelines, fittings, etc. can lead to leakage and uncontrolled gas infiltration — with all the related consequences [1-5]: explosions /fires devastating with material damage, human losses, the interrupting of gas supply to consumers, environmental pollution, etc.

In view of these considerations, the paper purpose is to analyse the factors that determine the durability and the operation safety of gas networks made with metallic pipelines.

2. Gas networks

Natural gas is transported from sources to consumers through high-pressure underground metallic pipelines (usually over 10^6 Pa).

Due to the high risk in exploitation, thoroughfare route of natural gas pipeline avoids the localities — they are exclusively outside the built-up areas. In the localities proximity there are "teaching stations" in which the gas pressure is reduced to less than $58,8*10^5$ Pa and the gases volume delivered to the local distributors is counted. Urban distribution networks usually have two pressure steps, medium pressure (usually 10^5 Pa-$58,8*10^5$ Pa) and low pressure. At this pipelines the household consumers (usually less than 10^5 Pa) are connected, and the connections are made through via control and metering stations (CMS).

In addition to pipelines, a series of components such as fittings, flanges, pressure regulators, counters, electric insulating fittings [6], etc., which have a wide variety of materials susceptible to ageing, are used in the gas networks. The main component of gas networks are pipelines. In the case of underground metallic pipelines, they are protected against corrosion.

The basic protection consists of insulation layers made of bituminous material [7, 8], which in the last decades has been replaced by layers of polymeric material (usually polyethylene) made by extrusion [9-11] or by successive layers of foil applied to warm [12-14]. In order to ensure a safe working exploitation of more than 25 years in addition to the basic (passive) anti-corrosion protection, the correspondingly designed cathodic (active) [15, 16] protection [17, 18] is also applied.

In the metallic components case of the overhead parts, the corrosion protection is achieved by painting, the paint layers being exposed to ageing due to continuous exposure to atmospheric weather, UV/IR and biodegradation [19-24].

The ageing of paint coats can be accelerated by accidental contact with petroleum products and/or fatty substances [25-28].

3. Stress factors of metallic gas networks

The main stress factors that act on gas networks are:

- mechanical stresses:
  - tensions due to displacements /landslides;
  - shocks and vibrations produced primarily by road transport;
- chemical aggression of soil by corrosion of underground steel pipelines;
- chemical aggression of the atmosphere (humidity, aggressive agents such as CO_2, SO_2, NO_x, moisture-retaining dust etc.) by corrosion of overhead pipelines and fittings;
- microbiological loading of the environment (soil and air) [29] by:
  - biodeterioration of the corrosion protection layers;
  - acceleration of steel corrosion processes (microbiological corrosion - MIC);
- electricity:
  - of anthropogenic origin:
    - electromagnetic pollution of the environment, DC and AC stray currents [30-32] by acceleration of the corrosion processes by anodic dissolution of the metal that can cause electric shock to the maintenance personnel and/or users;
  - of natural origin:
    - telluric currents [33, 34] that accelerate the corrosion of the steel by anodic dissolution;
    - static electricity loads, lightning strikes by pierce of anticorrosive insulation layers and/or electric shock of maintenance personnel and/or users.

4. Corrosion of metallic pipelines and fittings

From the point of view of stress factors and mechanisms of corrosion processes, in the case of gas networks it is differentiated in: underground corrosion and atmospheric corrosion.

4.1. Atmospheric corrosion of gas networks

The overhead metallic components of gas networks are exposed to natural weathering environments.

It is noted that in some areas atmospheric air can be intensely industrially polluted with dispersions of aggressive agents such as SO_2, NO_x etc. and dust [35-41] (which is being deposited on installations and retains moisture what it favours the formation and activity of corrosion cells).

Usually, metallic components are protected against corrosion by paint layers.

Under the action of stress factors specific to the exploitation environment, paint layers ageing through erosion, thermal-oxidative processes, biodegradation (growth of biofouling), etc. [19-24, 42-44].

Due to the ageing of the paint, the electric conductivity of the protective layer increases substantially. It also increases the permissiveness / diffusion of aggressive agents from the atmosphere through the paint, to the metal support.

Under these conditions, the paint layer loses its corrosion protection capability what it favours the formation and intensification of micro and macro corrosion cells.

4.2. Underground corrosion of gas networks

For technical and economic reasons, the pipelines of underground gas networks are traditionally made of carbon steel (reasonable costs, high mechanical strength, etc.)

The corrosion of underground pipelines is a complex process that requires a global approach to the system: metal / anticorrosive insulation / medium (ground).

The mechanisms of global underground corrosion processes are diverse. Different forms of damage to gas networks such as micro and macroporous corrosion, differential aeration, corrosion by stray currents, etc. are distinguished.

In all cases, the metal deterioration processes are due to limited thermodynamic stability of steel and differential electrochemical polarization, because anode area (polarized positively against the ground) and cathode area (polarized negative against the ground) are formed.

In this context, the methods of controlling (preventing and/or limiting) corrosion are:

a) passive methods by metal isolation against the ground:

- limiting the access of aggressive agents (depolarizers) from ground towards metal surface, thus limiting the supply and implicitly the activity of corrosion cells;
- electric insulation of the metal surface, against the ground, thus limiting corrosion currents, and corrosion cell activity;

b) active methods by the cathodic polarization of the steel surface against the ground (electrolytic medium) so that the global steel corrosion / dissolution process

$$Fe \rightarrow Fe^{z+} + z * e \quad (1)$$

where: z - valence; e - elementary charge /electrons freedom from to the dissolution of iron) to be thermodynamically impossible:

- with active anodes of sacrificial [18] connecting the steel with a more electronegative metal, such as zinc, placed in the same electrolytic environment (ground) with the protected steel, metal which by dissolution releases electrons that move the balance of

$$Fe \leftrightarrow Fe^{z+} + z * e \quad (2)$$

to the left;

- with cathodic current power supply (cathodic protection [15, 16, 45]) through which the protected steel cathodically polarizes against mounts of counter-electrodes (passive anodes - graphite, FeSi 14 % alloy, etc.) placed in the ground.

In practice, all underground pipelines are provided with a basic protection — a bituminous [7, 8] or polymeric [9-14] insulation layer — that provides passive protection, as well as the effectiveness of the active protection systems implemented.

Under these conditions, the durability of the underground metallic pipes is primarily determined by the integrity of the underlying protective layers.

Polymer layers for to the basic protection are in contact with the ground and, as in the case of underground power cables [47-55] they are exposed to chemical stressors (especially heat-oxidative [56, 57] and microbiological [58] processes in the ground.

Under the concerted, simultaneous and synergistic action of stress factors in the ground, the basic insulation aged and the protective layers lose their corrosion resistance.

A substantial contribution to the degradation of the insulation layers applied to underground metallic pipelines is made by the ground microorganisms, especially filamentous molds [58-64] whose mycelial hyfe penetrate into the protective layer material thus increasing the permeability /diffusiveness of aggressive species from ground towards surface of the metal and decreases the insulation resistance.

Under these conditions micro and macro corrosion cells activity increases significantly.

The ground microbial aggressiveness is enhanced by the presence of petroleum products (ground contamination with hydrocarbons [65-67]).

Recent studies [30, 68-72] showed that, under the influence of ultra-low frequency electromagnetic fields (ELF) — especially those with 50 Hz industrial frequency — metabolism, growth and multiplication of microorganisms is significantly stimulated, pipelines exposed AC stray currents [31, 32, 73] lead to accelerating the biodegradation of the protective polymer layers.

Due to enzymatic activity and metabolism products of ground microorganisms, corrosion processes of metals, including carbon steel, are significantly accelerated [73-82].

In situations where microorganisms and stray currents act simultaneously by synergy effects, corrosion of steel is greatly accelerated [83].

Electromagnetic environment pollution, disturbing signals generating stray currents are a stress factor with major implications in gas networks corrosion [45, 31, 32, 74, 84-92].

Due to excessive industrialization, electricity production and consumption show a steady growth trend, which leads to increased interference between electric networks and underground pipelines.

It is noted that the technological developments in recent decades have increased the share of reactive consumers (illuminated with LED, commutation power supply (AC /DC, AC /DC / AC, DC /AC /DC, DC /AC converters, etc.) harmonics and transients [93-98] that accelerate the ageing of polymeric insulation related to the basic insulation and through the depolarization of partially anodic processes leads to an increase in corrosion speed [99-104].

The disturbing signals generating stray currents are diverse. Mainly, they differ [74] by:

- DC stray currents: primarily from urban rail systems (subway, tramway [85, 104]), strictly through ohmic voltage drops
- AC stray currents: coming from the three-phase electric power system by:
    - Induction: from overhead power lines;
    - ohmic voltage drops: due to imbalance currents flowing between ground plates of earthing systems.

In this context, a special case represents electrified railway lines [74], which generate AC stray current both by ohmic voltage drops on the rails (in contact with ground) and induction from the contact line (usually supplied at 28 kV as industrial frequency).

The modelling and calculation of tensions induced by power lines in underground pipelines is a complex issue and has been the subject of numerous studies [32, 83, 84, 93, 105-109].

Traditionally, protection against dispersion currents in AC and against lightning has been achieved by implementing Rustol cell decoupling elements.

To eliminate the disadvantages of Rustol cells (size and high costs, expensive maintenance, etc.) solidstate devices [110-113] have been developed.

The solid state devices achieved has sizes and costs low deployment of implementation.

They have the ability to decode lightning strikes of at least 100 kA (standard impulse 20/8 μs) and ensures recovery the perturbing AC voltage at a reduced forward voltage drop (VF between 0.2 and 0.9 V) and converting to cathodic current of protection [114-115].

The corrosion caused by DC stray currents is different from those produced by AC stray currents. The DC stray currents act localized and in the anodic zones dissolve the steel — the mass of the dissolved steel Δm is [74] (1):

$$\Delta m = \frac{M}{z \cdot F} \int_{t_0}^{t'} I_A(t) dt \tag{3}$$

where: M - atomic mass of iron, z - iron valence, F - Faraday number, IA - current evolution during t.

According to (1) a DC stray current of only 1 A medium dissolves localized (on restricted area) 9.15 kg /year, which suggests the special danger of DC stray currents.

Destructions caused by DC stray currents are like deep craters, in the form of funnel-shaped that advances from the outside to the interior of pipelines (Figure 1).

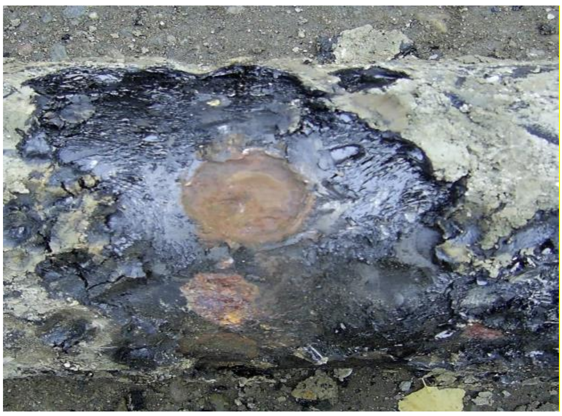

Figure 1. Typical image of corrosion by DC stray currents

AC stray currents produces both insulation degradation and acceleration of the global corrosion process by depolarizing the partially anodic process [74] — they produce generalized corrosion, extended on large surfaces, including by diminishing the effectiveness of any implemented cathode protection systems.

The most dangerous form of corrosion is that produced by simultaneous interference with AC and DC stray currents (as illustrated in Figure 2).

Figure 2. Underground gas pipelines with degraded insulation and corrosion generalized by the action of AC stray currents and pierced in the form of funnel by the DC stray currents

5. Corrosion Control Gas Networks: Intelligent and Preventive Diagnosis

Underground corrosion is a form of "cancer" of metallic pipelines but, with today's knowledge can be prevented and successfully treated by 100 %.

Of course, this involves knowledge of the mechanisms of action of stressors, respectively the implementation and the exploitation of modern and efficient protective methods and devices.

Preventing uncontrolled gas degradation and leakage, assessing corrosion status and safe gas lifetime of gas networks requires periodic developing intelligent preventive diagnostic studies [116-120].

These studies involve the periodic determination (on the land) of the main functional parameters such as pipelines /soil potential [15], insulation resistance of protective layers [12, 14, 56].

6. Conclusions

The Stress factors have been analysed to determine the durability and safe exploitation of metallic pipelines for gas networks.

Studies achieved have shown that during the operation, gas networks are exposed to mechanical stresses and electrical requests of anthropic and natural origin.

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