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Corrosion Protection: Maintaining and assessing the Integrity of buried pipelines with a particular view to water pipelines

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Introduction

Water pipelines suffer corrosion problems much more than gas or oil pipelines. This is due to various reasons such as:

- corrosion problems in water pipelines may arise either internally or externally;
- cathodic protection has not been mandatory for water pipelines up to now , at least in Italy;
- water leaks are much less dangerous and harmful than gas or oil;
- the cost of water has been so far considered not a problem.

In 2010 the Italian Authority of Energy and Gas has been charged by the government to follow up also water as a primary source; they are going to deliver new Rules in the subject of water pipelines maintenance and safety for the environment and pollution.

External corrosion in water pipelines can in general be paralleled to the one which occurs in gas or oil pipelines. Corrosion characteristics occurring in oil pipelines can be considered very similar (heavy weight of the pipe due to the liquid content, coating damages in the lower part of the pipe), but can be much more devastating due to the combined effects: internally for water corrosivity and water flow, externally for the lack of cathodic protection. Besides, many pipelines have been realized by using the “bell and spigot” coupling so that many of these joints are leaking, sometimes noticeably.

Drinking water can be, and really often is, very heavily polluted by corrosion products and at risk of pollution from the external environment, once corrosion has perforated the pipeline. While Pipeline Integrity Strategies, Techniques and Devices are well known in the petrochemical world, water pipeline industry seems not to be fully aware and accustomed to the use of the various important techniques which have been particularly developed for the gas/oil pipeline’s world.

The present paper aims to highlight the capabilities of these technologies and the limits and advantages of transferring them to water pipeline’s world.

1 – Foreword

In water distribution networks, the situation can be depicted as follows:

- networks date back to the middle of the last century and, in several cases, even before;
- materials used include cast iron and low alloyed steel, fiberglass and reinforced concrete;
- reduced budgetary availability for replacement and maintenance of existing piping by distribution companies have been conditioned, at least in Italy, by the very low fare cost of drinking water;
- last but not least, the mental attitude of these distributors to whom a blast or a leak of a water pipeline “only” implies a water flooding of a road and an interruption of water service; while something similar in an oil or gas pipeline can lead to a disaster.

The historical situation has led to this: In the 50ies of the last century, water supply networks have been realized by using cast iron (30 – 40% of the network), mechanical coupling and rubber seals, while an equivalent quantity of water pipelines have been realized with a poor quality steel and connected with the “bell-and-spigot” type of joining.

The coating (if there was a coating) was only limited to steel pipelines and was realized by a simple layer of bitumen applied with primitive methods. In Northern Europe there was also quite a quantity of asbestos-cement pipelines.

The renewal of the piping, around 70ies- 80ies, was mainly devoted to grey cast iron pipes, replaced by spheroidal graphite for which an external coating was thought not necessary. This concept was soon disproved by numerous cases of corrosion occurred, due to local, geological cells, mainly in clayey soils.

In the mid- 80ies cathodic protection of ductile iron pipes begun, but the joints were always of mechanical type with rubber gaskets electrically isolating each pipe spool.

In the same period the use of steel pipes with double ring mechanical joints made of rubber, lined with concrete and externally coated with one-to three layers of polyethylene applied by hot extrusion. Always there was the problem of the poor electrical connection of the joints between the pipe spools.

In this period also the use of fiberglass piping started, only for medium-high diameter pipelines.

In the early 80ies the use of HDPE (High Density Polyethylene) also begun, starting to connect the main low pressure pipelines to the end users (up to 80-100 mm diameter), later on extended to pipes from reservoirs and from piezometric towers to the end users. For these last type of pipelines HDPE has been used up to 200-250 mm diameter. As a result, the techniques of Cathodic Protection in water distribution pipelines can only be applied to that part of the network connecting the primary collection points (i.e. the wells and reservoirs, purification and treatment stations) and from these to hilly/mountainous residential areas and to Water Towers for low-laying areas.

2 – The value of water in the European Countries

An interesting and we think fundamental aspect of water transport and distribution in Europe is its relative value. Figure 1 shows the losses of water in various European Countries, as determined in a research dated 2008.

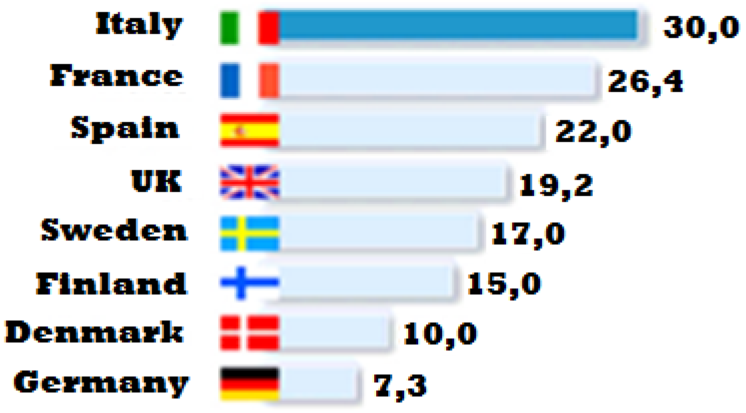

Figure 1 – Water losses in the European Network (% of Water entered in the net and not invoiced) **Source: elaboration on Data Civicum, Study Office Mediobanca, 2008**

In spite of being the first position for water losses, the average cost of water in Italy (Figure 2) is 6 times less than in Germany or in Denmark then, a simple elaboration shows that, on the other side, the value of these water losses (Figure 3) has been and still is very low in Italy. This fact automatically implies that the value of water has not been considered important since now, hence the scarce interest for investments and lack of care for water pipelines integrity.

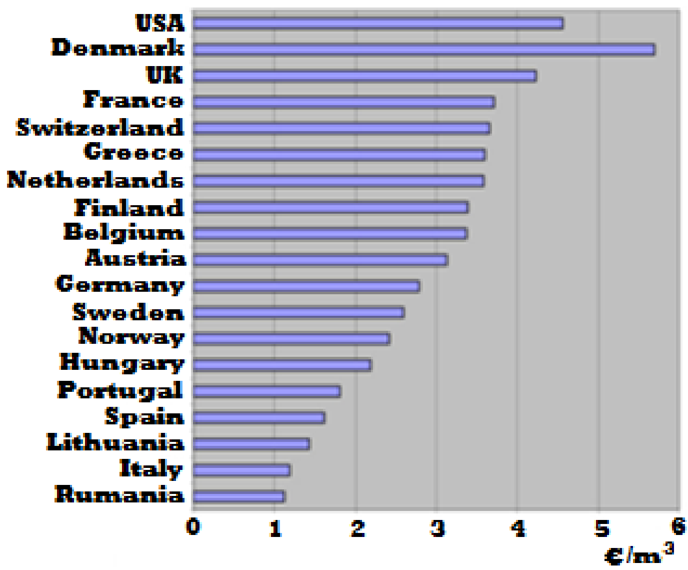

Figure 2 – Average cost of Water in various Countries Source: elaboration of Data A. Morassutti, 2011

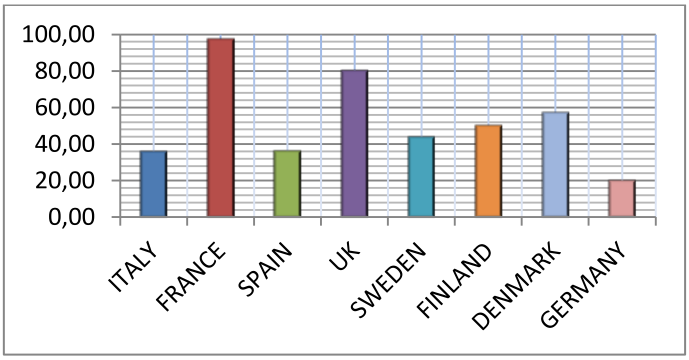

Figure 3 – Relative value of Water Losses in some European Water Network

3 – Gas & Oil Authority in Italy

The Regulatory Authority for Electricity and Gas (**Aeeg**) is the independent body which regulates, controls and monitors the electricity and gas markets in Italy.

The Authority has been established by law (November 14th 1995, n.481) with the purpose to protect the interests of users and consumers, promote competition and ensure efficient, cost-effective and profitable nationwide services with satisfactory quality levels.

Aeeg mission includes defining and maintaining a reliable and transparent fare system, reconciling the economic goals of operators with general social objectives, and promoting environmental protection and the efficient use of energy. It provides an advisory and reporting service to the government and parliament, and formulates observations and recommendations concerning issues in the regulated sectors of electricity and gas.

3.1. – The new Competences of Aeeg on Water service

With the Decree-Law No. 201/11 (the so-called 'save-Italy '), converted into law No. 214/11, the authority for electricity and gas (**Aeeg)** has been attributed power also for water services. In fact, the article 21, paragraph 19, provides in particular that: '*with regard to the National Agency for regulation and supervision in the field of water, are transferred to the authority for electricity and gas regulation and related functions for the control of water services, which are carried out with the same powers granted to the authority itself by law No. 481 November 14, 1995* '.

The same Act also establishes that the functions to be transferred to the authority shall be traced by Decree of the President of the Council of Ministers (DPCM), upon proposal by the Minister of the environment and protection of land and sea (MATTM), to be emitted within 90 days from the date of entry into force of Decree-law.

As a result of these new legislative forecasts, in its meeting dated December 29, 2011, the authority has approved the Resolution 63/11 GOP with '*First provisions relating to transfer authority for electricity and gas regulation and control functions of water services, in December 22, 2011, law No. 214* ". With this measure the Authority initiated the necessary steps to ensure full cooperation and help accelerate the transition process under way; in particular, the GOP resolution 63/11 provides the adoption of all initiatives and appropriate contacts with the Ministry of the Environment through working groups at different levels, for the definition of functions to be transferred to the authority. Also with resolution 29/2012/R/idr dated February 2, 2012 the authority has set up a working group dedicated to the preliminary, preparatory and precognitive activities, to be completed within May 31, 2012, in view of the forthcoming full operation of the new asset.

Authority for Electricity and Gas Water - Milan, December, 2012 - Press Agency

65,00 Billion Euros is the sum to fight pollution and waste, to guarantee the right to water not only on the paper – coming soon a new fare method to develop the infrastructure and give new impetus to the **Water Sector**. The goals are to ensure the right to water, combating waste and pollution, develop the infrastructure through innovative adjustment, attentive to the quality of service and social protection.

These are the main Guidelines of the action of the Authority for Electricity and Gas in the new Water Services Sector after the allocation of these functions of Regulation and Control with the Decree 201/11, the so-called ' Save Italy Decree '.

Water is a Sector penalized by obvious weaknesses: losses in the network by more than 30%, the highest in Europe; 5% of the Italian population has no sewer systems, insufficient or even non-existent cleaners for an Italian on three and discontinuity in water delivery, especially in Southern Italy. All this with an impact to the environment and the health, not to mention the damage to agriculture and tourism, including potential European sanctions.

In order to address and overcome these problems, according to data submitted under plans already approved, over 65 Billion Euros will be allocated for assistance over the next 30 years.

4 – The integrity of water networks

The increased cost of water and the implications of its possible pollution due to corrosion are then changing the scenario and will certainly ameliorate the integrity of water pipelines.

4.1. Internal corrosion

The main aspects tied to internal corrosion may be summarized in the following categories:

- water corrosivity
- water flow
- cathodic protection

4.1.1. Water corrosivity

The corrosivity of water should be considered by careful, continuous analyses of water contaminants. Antifouling and addition of proper products must be considered.

In the following list, some of the principal physical and chemical parameters of water that can influence corrosion in a water conveying system.

- *Temperature*
- *pH*
- *Conductivity at 20ºC*
- *Total hardness (concentration of Ca + Mg soluble components)*
- *Calcium hardness (concentration of Ca soluble components*
- *Alkalinity (down to pH 4.2)*
- *Acidity (up to pH 8.2)*
- *Dissolved oxygen*

- *Suspended solids*
- *Total dissolved solids*
- *Chloride ions*
- *Nitrate ions*
- *Sulphate ions*
- *Phosphorous compounds*
- *Silicon compounds*

Certain inorganic and organic species naturally occurring in water can inhibit corrosion reactions by assisting in the formation of protective layers. These include phosphates and silicates. Waters from lakes and rivers generally contain a higher level of decayed organic matter than water from bore holes, which can help compensate for their lower hardness.
Of vital importance for the corrosivity of water is the concentration of anions, in particular chloride and sulphate ions. The presence of these anions increases the likelihood for pitting corrosion of certain metals and alloys.

4.1.2. Water flow

Between the two boundary cases of water flow conditions (full flow – water stagnation) a large variety of water flow conditions is possible in the same system.
The corrosion likelihood is influenced mainly by the frequency and the velocity (or, more precisely by the Reynold's Number) of water flow.
Long stagnant periods facilitate the stabilization of local corrosion cells and the onset of pitting attack. In addition, very low flow rates can allow deposits to settle out in the system or may not dislodge existing deposits, thereby creating the likelihood of pitting corrosion under deposits. High local flow rates, depending on geometry, induce turbulent flow that can cause erosion corrosion by removing protective surface films.

4.1.3. Interference due to Cathodic Protection or d.c. stray currents

In some particular cases, it may happen that the application of Cathodic Protection for the external surfaces of the pipeline can imply a high difference of electrical potential across the insulating joints. such as to give rise to the internal corrosion of the pipeline (Figure 4).
The same phenomenon may happen also when this kind of interference is due to other sources such as, for example, d.c. stray current interference.

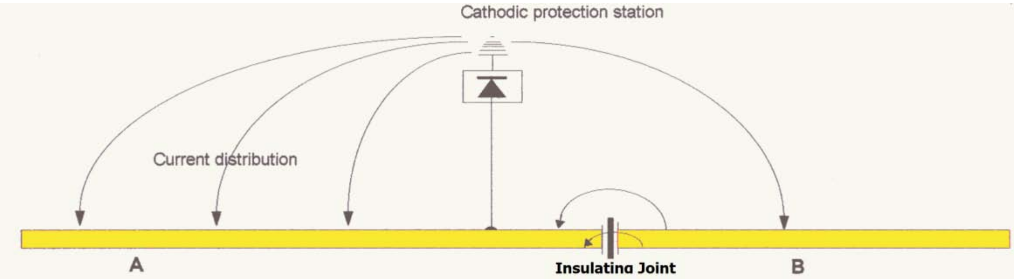

Figure 4 - Internal corrosion due to electrical interference

4.1.3.1. Likelihood of internal corrosion due to electrical interference

In the presence of an external interference, the possibility that internal corrosion will take place and its entity will depend on numerous factors such as:

• a potential difference between both sides of the insulating joint;
• the longitudinal ohmic resistance in the metallic circuit (the insulating joint);
• the presence of an electrolyte with high conductivity in the internal part of the pipe.

4.1.3.2. Seriousness of the corrosive attack

The seriousness of the corrosive attack will mainly depend on the following parameters:

- the amplitude of potential difference between the two sides of the insulating joint;
- resistance of the electrolytic path across the joint, where the main parameters who play a role are:
  - the conductivity of the electrolyte;
  - the quantity of electrolyte;
  - the time of presence (e.g. periods of stagnation or inactivity) of the electrolyte, its presence in the lower part of the pipe;
  - the ratio between anodic and cathodic areas close to insulating joint.

Some interesting works have been performed within an ad-hoc working Group of Ceocor and published during a previous Ceocor Congress showing the importance of calculating the internal coating length of these joints (Figure 5);

- the internal and external coating conditions across the insulating joint must be carefully verified;
- the possibility of installing a special piece for this transition part should be considered (e.g. installation of flanged, plastic pipes (e.g. PE pipes), whose length is a function of the resistance of the electrical path between the internally isolated parts of the pipe);
- the electrical interference between the upstream and downstream sections of these joints must be continuously controlled during the routine maintenance measurements of the Cathodic Protection System; unbalanced potentials across the joint can give rise to either internal or external interference corrosion.

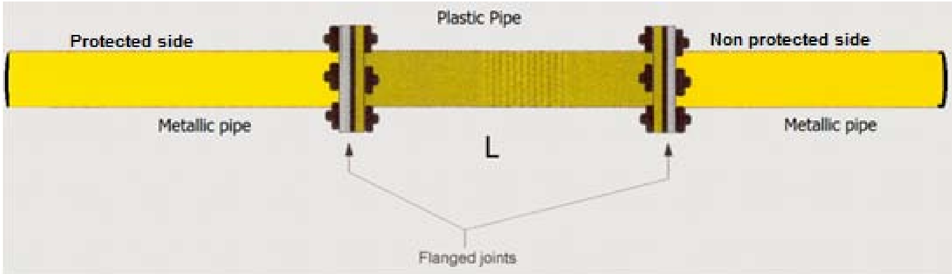

Figure 5 – Installation of a transition piece as insulating joint for water pipelines

The length L of these transition isolating pieces are to be calculated according to the following Schwenk formula:

$$L = 5 * V * \sqrt{\frac{r}{\rho * Vcorr}}$$

L	*Length of isolated section (m)*
V	*Potential difference between the two sides of the insulating joint (V)*
r	*pipe radius (cm)*
ρ	*water resistivity (Ohm.cm)*
Vcorr	*accepted corrosion rate (mm/year)*

The following graph shows the length L of the isolated section of pipe to be adopted in the hypothesis that the difference of potential between the two sides of the Insulating Joint is 1 Volt, and the accepted corrosion rate is 1 mm for 20 Years.

An important consideration is that the isolated Section must be installed in the cathodic side of the circuit (usually the line side, were the pipeline has a higher level of CP or, in any case, where it's potential is more negative). In order to reduce the potential difference between the two sides of an insulating joint, an electrical balancement of them could be provided or the installation of local sacrificial anodes could also be considered.

4.2. External corrosion

During the various phases of design, construction and operation of gas and oil pipelines, experts around the world are aware of the "corrosion risk due to the external environment" and apply a set of rules based on three main points, supported by consolidated international technical regulations:

- steel pipes are welded;
- they are protected by an external coating up to 3 layers and
- provided with Cathodic Protection Systems, often automatically handled

Such rules prevent corrosion of pipelines and ensures long life and continuous and safe operation.

In addition to gas and oil pipelines, which may consist of pipelines having a diameter up to 2.00 m and lengths of some hundred kilometers, the three above mentioned features also apply to urban distribution networks and long distance pipelines at medium pressure (up to 10 bar), but not to the capillary distribution networks of gas to low-pressure city utilities, where there is a tendency to use HDPE pipes, especially for replacing cast iron and steel pipelines installed since the middle of the last century.

Old water pipelines need a careful verification of the external coating conditions so that, consequently, cathodic protection levels can be measured. Most of existing water pipelines are provided with old bituminous materials and show a very low insulation resistance. Wherever the coating is very poor, with consequent very high cathodic protection absorbed currents, it is worth doing specific coating surveys. In these cases an Electromagnetic Current Attenuation Survey can be considered as a first, low cost step to localize macro-regions where the coating needs more attention.

The second step is to isolate the pipeline in Sections autonomously protected, if possible by a single CP System; Insulating Joints are to be installed, if required, in proper positions.

When a water pipeline is leaking, a very low insulation value can be observed around the area where the leak is present. The continuous Monitoring of the insulation conditions of a water pipeline is a viable option in this case.

Modern technologies allow to easily install a Remote Control System for continuous detection of Cathodic Protection operating conditions (Current, Voltage, Potential, at the CP Station). These Systems, with a proper Software, are able to continuously calculate the Insulating Resistance Value of quite length Sections of pipeline under control, giving rise to alarms in case the insulation resistance has important, anomalous variations (mainly towards lower values).

For water pipelines which are not provided with a cathodic protection system, the following steps are suggested:

- Feeding Tests to verify the possibility to cathodically protect the pipeline;
- Subdivision into sections protected by a single Cathodic Protection System; the installation of insulating joints should be considered;
- Once the pipeline has been duly subdivided, perform an Electromagnetic Current Attenuation Surveys to localize areas having the lower isolation conditions. This

kind of survey is usually made starting at measurement intervals of 500 to 1000 m, but this distance can later on be reduced to 50 or even to 10 m;

- A careful examination of the sections showing the lowest isolation (for example by using the Transverse Gradient Measurement technique) allows to better localize possible short circuits, contacts or other places where the coating is to be repaired or substituted (interval of measurement surveys 5 m or less);

In case of water leaks, the soil resistivity around the area of leak will have an evident variation of its soil resistivity. This will automatically be associated to a higher C.P. current requirement for the involved area.

Obviously, it is also possible to make a leakage survey by using the classical methods (e.g. acoustic leak detectors).

Once the pipeline has been recovered to normal good conditions, and is cathodically protected, a continuous monitoring of its isolation resistance is possible by using an Automatic, Remotely Controlled CP Station.

The unit is composed of:

- Remotely controlled CP Station
- Permanent Reference electrodes
- A devoted Software

More in detail, the parameters of interest which can be kept under control are the following:

- Ris = Isolation Resistance (Ohm*m^2)
- $V_{on} - V_{off}$ = Potential variation (mV)
- ΔI = Current variation (mA)
- S = Surface interested by the CP current (m^2)

From these parameters, the Isolation resistance can be continuously monitored:

$$R_{is} = \frac{(V_{on} - V_{off}) * S}{\Delta I}$$

This technique has been developed in the 90ies for monitoring the impact of a mechanical machine on a gas pipeline and proved to be able during the tests in real scale to automatically generate alarm signals if the impact was at 7 km distance from the monitoring equipment. This distance can also be much longer, depending on the conditions of the coating. In case of an impact due to a mechanical machine, the isolation resistance variation is sudden and remains only temporarily while in case of water leaks, the variation is much more consistent, remains during time and eventually increases (the insulation resistance continuously decreases). This allows to assume that the application of this kind of monitoring system for the isolation resistance of water pipelines could be more simple and profitable.

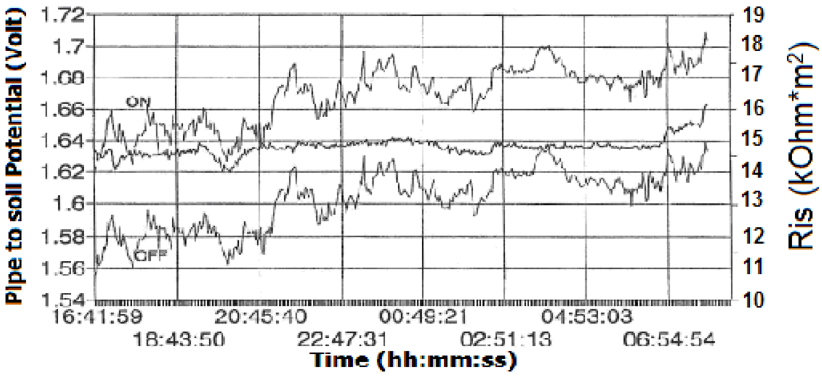

Figure 6 – Continuous Monitoring of the Isolating resistance of a pipeline

5 – Conclusion

Drinking water is nowadays considered a valuable primary source and, as such, not different from energy sources like oil and gas. While in the oil and gas industry all over the world some techniques have been fully developed and are in use since many years ago, in the water world, due to the scarce value involved with water until recently, these techniques are not well known or not used. Usually the leak detection for water pipelines is part of a general maintenance plan. This is normally made on yearly basis, covering various areas suitably subdivided. Various methods can profitably be used for monitoring pipe corrosion conditions and water leaks such as intelligent pigs (Leak Detection or Ultrasonic e.g. SmartBall®or Magnetic Flux Leakage Pigs, video-camera inspections).

Water operators are accustomed to deal with problems related to water corrosivity, incrustations, the use of inhibitors and other internal corrosion problems on their pipelines. In order to cope with external corrosion, especially for old, existing water pipelines, it is essential to recover the conditions for their cathodic protection. In addition to the above said mentioned and referenced methods, once the recovering of water pipelines has been attained, also using techniques such as the Electromagnetic Current Attenuation Methodology, the Monitoring System mentioned in this paper could profitably be applied to water pipelines, after their rehabilitation and once the cathodic protection system has been revised and updated. A correct approach is also suggested to avoid internal corrosion due to Stray Current Interference across insulating joints on water pipelines.

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