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Paper A06 - Corrosion and Cathodic Protection Aspects of Pipeline Integrity

L. Di Biase - ISPROMA Scientific Advisor – Italy l.dibiase@isproma.com
R. Cigna - ISPROMA – Italy r.cigna@isproma.com
O. Fumei - ATECHMA – France atechma@wanadoo.fr

Abstract

New rules and obligations are more and more worrying pipeline integrity managers all over the world. Public Authorities are issuing rules and obligations for pipeline operators while safety and environmental issues become more stringent in the high competitive market of energy.
An important part of a Pipeline Integrity Management System concerns old/very old pipelines which usually cannot be controlled by intelligent pig inspections. Cathodic Protection installations, maintenance plans, the evaluation of field measurements and specialised electrical surveys are very important when an official evaluation has to be assessed concerning the integrity of buried pipelines transporting hydrocarbons (mainly gas and oil).
Authorities must be fully and correctly informed so that their rules have the most possible efficacy and efficiency. This is not so straightforward as it seems to be in abstract; experience demonstrates that even among CP and Corrosion experts and pipeline integrity managers it is sometimes difficult to examine and evaluate corrosion phenomena and their consequences in the same way.
The paper, considering the evaluation of the results of CP measurements and electrical surveys and bearing in mind the corrosion case histories concerning d.c. or a.c. Corrosion, Microbial Corrosion, Stress Corrosion Cracking, aims to discuss their interpretation in terms of Risk Factors for evaluating Pipeline Integrity.

Key Words
Cathodic Protection, Corrosion Threats, Electrical Surveys, Pipeline Integrity, Risk Indexes

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A06 - Corrosion et aspects relatifs à la protection cathodique de l'intégrité de la canalisation

Résumé

De nouvelles règles et obligations préoccupent de plus en plus les responsables de l'intégrité des canalisations dans le monde entier. Les pouvoirs publics édictent des règles et des obligations à respecter par les opérateurs de canalisations, tandis que la sécurité et les questions environnementales deviennent de plus en plus strictes sur le marché très concurrentiel de l'énergie. Un système de gestion de l'intégrité des canalisations concerne en grande partie des canalisations anciennes/très anciennes qui ne peuvent généralement plus être contrôlées par des inspections par racleur intelligent. Des installations de protection cathodique, des plans de maintenance, l'évaluation des mesures de terrain et des études électriques spécialisées revêtent une importance capitale lorsqu'il s'agit d'apprécier une évaluation officielle concernant l'intégrité des canalisations enterrées transportant des hydrocarbures (essentiellement du gaz et du pétrole). Les autorités doivent être totalement et correctement informées afin que leurs règlements soient les plus efficaces possible. Cela n'est pas si évident qu'il n'y paraît en théorie ; l'expérience montre que, même parmi les experts en protection cathodique et en corrosion et les gestionnaires de l'intégrité des canalisations, il est parfois difficile d'examiner et d'évaluer de manière uniforme les phénomènes de corrosion et leurs conséquences. L'article, se basant sur des mesures réelles de protection cathodique, des études électriques et des cas concrets de corrosion tels que la corrosion c.c. ou c.a., la corrosion microbienne, la fissuration de corrosion sous tension, vise à examiner leur évaluation éventuelle au niveau des facteurs de risque pour évaluer l'intégrité de la canalisation.

Mots-clés Protection cathodique, menaces de corrosion, études électriques, intégrité de la canalisation, indices de risque

Zusammenfassung

Neue Regelungen und Auflagen erregen weltweit bei den Zuständigen für Pipeline-Integrität immer mehr Besorgnis. Die Behörden veröffentlichen stetig neue Regelungen und Auflagen für Pipeline-Betreiber. Gleichzeitig spielen die Themen Sicherheit und Umwelt im hochgradig wettbewerbsorientierten Energiemarkt eine immer wichtigere Rolle. Ein wichtiger Teil eines Pipeline-Integrität-Management-Systems betrifft alte bzw. sehr alte Leitungen, die in der Regel nicht mit intelligenten Molchen inspiziert werden können. Kathodische Schutzvorrichtungen, Wartungspläne, die Bewertung von Feldmessungen und spezielle elektrische Prospektionen sind äußerst wichtig, wenn eine offizielle Evaluierung der Integrität im Boden verlegter Pipelines zum Transport von Kohlenwasserstoffen (insbesondere Gas und Öl) erfolgen muss. Die Behörden müssen vollständig und korrekt informiert werden, damit die von ihnen erlassenen Regelungen die bestmögliche Wirksamkeit und Effizienz entfalten. Dies ist nicht so einfach, wie es laut dieser Zusammenfassung zu sein scheint. Erfahrungen zeigen, dass es auch Experten für kathodischen Schutz (*Cathodic Protection*; CP) und Korrosion sowie Pipeline-Integritätsmanagern manchmal schwer fällt, Korrosionserscheinungen und deren Auswirkungen angemessen zu prüfen und zu bewerten. Das vorliegende Dokument behandelt reale CP-Messungen, elektrische Prospektionen und Fallstudien zur Korrosion (z. B. durch Gleichstrom oder Wechselstrom), mikrobielle Korrosion, Spannungsrisskorrosion. Es bildet die Grundlage für die Erörterung einer möglichen Evaluierung der Risikofaktoren, die bei der Bewertung der Pipeline-Integrität eine Rolle spielen.

Schlagwörter Kathodischer Schutz, Korrosionsgefahren, elektrische Prospektion, Pipeline-Integrität, Risiko-Indizes

1 – PIPELINE INCIDENTS

Oil and gas utilities are legally required to maintain their technical systems in proper conditions and to meet all relevant safety requirements in order to guarantee maximum security of supplies at all times. This means to ensure the overall “integrity” of the systems which is mainly regulated at international level from TS 15173 and 15174 of CEN and ANSI B31 8S, further to National rules.
EGIG (the European Gas Pipeline Incident Data Group) is the largest organisation in Europe (15 gas Companies from various Countries participating nowadays); its reports provides a large and proven DATA BASE of gas pipeline incidents. Transmission companies of fifteen European countries collect incident data on almost 130.000 Km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 3,15 million Km*year. The failure frequency have been reducing over the years, although the rate of reduction has slowed in the recent years.
As far as incidents are involved, the most recent data available, relevant to the period 1970-2007 are shown in Figure 1.

GAS PIPELINE INCIDENTS

Cause	Overall Percentage %
External interference	49,6
Construction defect / Material failure	16,5
Corrosion	15,4
Ground Movement	7,3
Other or unknown	6.7
Hot-tap made by error	4,6

Figure 1 - Distribution of incidents per cause [1]

The major cause of incidents remains external interference, followed by construction defects/material failures and corrosion. Early built pipelines had a higher failure frequency due to corrosion, in their early years, than recently constructed pipelines. In recent years, due to improved maintenance, pipeline age has no longer a major influence on the occurrence of corrosion failures [2] .

2 – MANAGEMENT OF PIPELINE INTEGRITY

The durability of a system is its ability to perform the required function over a period of time and under the influence of external agents. The service life of a system is defined as the actual period of time during which no excessive expenditure is required for operation, maintenance or repair. A properly designed and maintained pipeline is an extremely safe way of transporting energy (e.g. hydrocarbon products such as oil and natural gas). Nevertheless, the reliability of pipeline’s operation can be impaired by various factors.
In order to cope with the many factors which could impair the safety and overall reliability of a pipeline (safety of internal personnel and the public, damages from or to third parties, reliability of transportation), most pipeline owners and operators have set up pipeline integrity management systems that enable the evaluation of all levels of pipeline incidents.
The various levels of this type of Systems are usually as follows:

a – Safety Management System (SMS)

Safety Management Systems (SMS) is the term used to refer to certain regulatory and enforcement frameworks. These frameworks generally apply to transportation industries, but have also been explored in other industries. This approach puts increased reliance on industry to cultivate a safety culture in order to enhance safety, and as such is a form of performance-based regulation.
It is a systematic, explicit and comprehensive process for managing safety risks. As with all management systems, a safety management system provides for goal setting, planning, and measuring performance. This System has been firstly applied to aviation, then to transportation of hydrocarbons, such as oil or gas.
In practical terms, it requires that the industry institute policies and systems designed to reduce risk, such as by implementing reporting systems for the reporting and correction of shortcomings [3] .

b – Pipeline Integrity Management System (PIMS)

PIMS aims to guarantee the safety of staff and the general public, to protect the environment, and to ensure the reliability of pipeline operation while making allowance for technical and economic requirements. A Pipeline Integrity Management System deals with the following key aspects :

- Technical Safety
- **Pipeline Integrity**
- Safety Management System
- Emergency Planning
- Land use Planning
- Public Consultation
- Role of Competent Authorities

c – Pipeline Integrity (PI)

The Pipeline Integrity aspect is one of the above said aspects and is represented by all those activities aimed at the safe and reliable functional integrity of a pipeline such as:

- maintaining the pipeline in a fit for purpose conditions;
- guarantee safety for people;
- guarantee the fluid transportation;
- reduce at the minimum the risk of environmental damages.

In this overall context the Public Authorities, mainly in the US, are playing a leading role in the control and verification of Pipeline Integrity. As a result of regulatory changes in the US, the pipeline industry needed alternative methods to pressure testing or in-line tool inspections to assess pipeline integrity. The Department of Transportation (DOT) of the US has adopted a new safety regulation whose effect has started since May, 2001. According to its requirements, pipeline operators are bound to implement a risk-based pipeline integrity program. Other important actors at international level (IGU, EGIG) as well as at National level (e.g. Public Authorities for Gas and Water) are issuing important trends and statistics based on which more and more stringent Rules and Recommendations to maintain under control the safety and integrity of pipeline systems are being issued.

3 – CORROSION AND CATHODIC PROTECTION ASPECTS OF PIPELINE INTEGRITY

As it has been shown (Figure 1), corrosion is the 3rd cause of incidents in gas pipelines. A further step following the above said framework is the one necessary to set up a system to take into account Corrosion and Cathodic Protection Aspects of Pipeline Integrity.

In the US, the External Corrosion Direct Assessment (ECDA) method has been implemented since 2001.

Quite all pipeline operators of oil, gas and other hydrocarbon products are nowadays obliged to verify their structures conforming or at least taking into account the above said rules. The results of this assessment are officially given to Authorities whose main task is to verify that the shortcomings are being solved or, at least, kept under control.

An important part of a Pipeline Integrity concerns old/very old pipelines whose corrosion conditions cannot be usually controlled by intelligent pig inspections; specific conditions also exist that impede to run intelligent pigs along a pipeline (low pressure/quantity of gas, too short radius bends, not full bore valves and others.

Mainly in these cases Cathodic Protection installations, their maintenance plans, the evaluation of field measurements and specialised electrical surveys are very important when an official evaluation has to be made concerning the integrity of buried pipelines transporting hydrocarbons (mainly gas and oil).

This means that it is necessary to:

- organise a Data Base of the Pipeline Network;
- input all the pertinent parameters for each pipeline or section of it;
- maintain an interactive set of data concerning:
    - CP systems;
    - Periodic maintenance measurements;
    - Electrical surveys;
    - Extraordinary measurements;
    - Data obtained from excavations (bell-hole examination);
    - Data on repairs/rehabilitation.

4 – TOOLS FOR MAINTAINING PIPELINE INTEGRITY

A set of tools are nowadays available and used for maintaining Pipeline Integrity, such as:

a. Intelligent pig inspections
b. Cathodic Protection Monitoring
c. Specialised Electrical Surveys
d. Visual inspections against third party interferences
e. Monitoring of soil stability
f. Metallurgical investigations for pipe steel/weld metal decay
g. Excavations for coating/pipe integrity inspection

As far as corrosion and Cathodic Protection are concerned, the items ***b*** and ***c*** are of interest and, indirectly, soil stability and external interference could be covered in certain circumstances by the above said items. It has been demonstrated with field measurements that some damages to the coating due either to external interference or to landslides/soil movements can also be detected with an accurate use of CP Monitoring Tools and/or by using the results of repeated electrical surveys.

4.1. - Use of Cathodic Protection and Electrical surveys for pipeline integrity purposes [4]

On gas pipelines, internal corrosion is hardly ever a problem, as the treatment of the gas transported guarantees a low level of humidity and a high degree of purity. Then, especially for gas pipelines, corrosion is generally referred to the outer surface of pipes, wherever the coating has failed.
When talking about external corrosion of buried pipelines, the following general categories and subsequent causes are to be taken into consideration:

- ***General corrosion***
  - CP is not sufficient;
- ***Microbial corrosion***
  - shielding effect, CP not sufficient, mainly under disbonded coatings;
- ***d.c. interference corrosion***
  - presence of coating faults, CP potential not sufficiently negative during worst d.c. interference;
- ***a.c. interference corrosion***
  - presence of alternating voltage on the pipeline/presence of small/very small coating faults;
- ***Low pH (near neutral) Stress Corrosion Cracking***
  - CP potential not sufficiently negative, presence of shielding effect, presence of high level mechanical stress;
- ***High pH Stress Corrosion Cracking***
  - CP potential not sufficiently negative, high temperature, presence of high level mechanical stress.

When a large pipeline network is involved, in order to prioritise and have clues about the problems that could occur on each of the pipelines or a section of them, a thorough analysis of pipeline age, type of coating, soil and environmental characteristics should be made in order to obtain a ranking among various elements such as:
- age of pipeline (new laid pipelines, old pipelines);
- corrosion cases previously detected;
- number of CP Stations per Km of pipeline;
- average CP current density related to the type of coating and soil resistivity;
- presence of d.c./a.c. interferences
- possibility of occurrence (likelihood) of disbonded coatings (especially with older type of cold applied tapes)
- presence of landslides/soil movement

3 – POLICIES, RULES AND STANDARDS

Corporate Policies indicate general rules of good technique to pipeline engineers to:

- lay pipelines far from existing urban areas or areas where urbanisation is foreseen;
- reduce the impact for pipe laying (cost for third party reimbursement for properties occupation or value reduction);
- follow most leaning lines on mountains or where different levels have to be overcome;
- avoid unstable or erosion areas;
- prefer river crossings with underwater techniques;
- avoid water table or flooding areas.

Unfortunately, most of existing pipelines have been laid, all over the world, since around 50 years ago and even more by adopting techniques, resources, knowledge which were available at the time of the construction.

As far as Corrosion and Cathodic Protection are involved, the following main Standards apply:

At International level:

ISO 15589 Petroleum and natural gas industries :

Cathodic Protection for pipeline Transportation Systems

- Part 1 - On-land pipelines
- Part 2 - Offshore pipelines

At European Level:

- Standard EN 12954.

4. – TYPES OF CORROSION

In can be useful to review the most common types of corrosion to be take into consideration, their possible origin, their physical and electrochemical characterisation.

4.1. - General corrosion

When general corrosion may occur at open coating faults in the pipeline steel, in most cases CP current could not be sufficient. CP measurements are generally performed only on test points which, in case of long land-crossing pipelines, can be at 1 km or even more distant from each other. The global current density is to be verified all over the pipeline, taking into account the soil resistivity, the presence of river crossings or other concentrated low isolation structures such as valves, weighted section of pipeline (e.g. on flooding areas) and similar.

A good tool to verify the current demand along a pipeline could be the Electromagnetic Current Attenuation method which allows a quick survey whose results give very good information on the overall conditions of the coating and current demand (Electromagnetic Attenuation is directly related to the CP current demand).

4.2. - Microbial corrosion

Due to its peculiar characteristics, Microbial Corrosion can only take place where the pH is low/very low. If Cathodic Protection is efficient, even large coating faults can be reached by a certain amount of CP current, thus elevating the pH at the pipe-to-soil interface to values more than 9 and much higher, according to the current density and local conditions.

Quite often, Microbial Corrosion is the result of a shielding effect, whichever the cause is, then the CP current is not sufficient to increase the pH of the environment, so that Microbial Bacteria can grow. This mainly happens under disbonded coatings of pipelines.

Corrosion under disbonded coatings is one of the aspects that Cathodic Protection or modern techniques against corrosion is still not able to solve. When a pipeline is suspected to suffer from disbonded coatings because of previous cases discovered, or because of its construction characteristics (e.g. cold applied tapes, especially those laid on the 70ies), an accurate monitoring of pipe to soil potential, combined with a specific fault location survey could give reliable results. Usually the apparent potential measured over the soil is rather satisfactory (e.g. -1,2 - -1,3 V), but the current on the section under measurement is quite low. A good technique may be to noticeably increase the current used for the Electrical Survey. The knowledge of the pipe-book and the history of its construction can give a great help.

4.2. - *d.c. interference corrosion*

When a pipeline is interfered by traction system powered in d.c., the presence of coating faults nearby the return circuit (Substation areas), could give rise to quick corrosions if the CP potential is not sufficiently negative during worst d.c. interference. The use of proper Drainages and automatically controlled CP Rectifiers is a must. But always the real point is to know where the worst case interference is present (during time and along the whole the pipeline).
Proper Monitoring of potentials and currents, together with Electrical surveys can greatly help solving the problem and assessing that the whole pipeline is protected even in the works case interference.

4.3. - a.c. interference corrosion

Especially on new laid pipelines, the presence of alternating voltage on the pipeline and presence of small/very small coating faults is a pre-condition for a.c. corrosion. Means exist to reduce the a.c. voltage level below the recommended limits (10 or 4 V, according to the European Technical Specification EN TS 15280 – Dec. 2001). In the presence of long parallelisms with High Voltage Power lines, or when higher voltages are present on the pipeline, a thorough electrical survey is very useful to discover small/very small coating faults. a.c. voltage measurements are not so easy to be made in these cases. The a.c. interference varies during the days being tied with the phase currents on the parallel line. Careful long-term data logging is necessary in strategic positions. The use of a.c. corrosion coupons and relevant data loggers is highly recommended.

4.4. - Low pH (near neutral) Stress Corrosion Cracking

This type of corrosion can only happen if the potential is not sufficiently negative (presence of shielding effect, partially disbonded coating and a quite high level of mechanical stress). Some experiences of Trans-Canada pipelines in the 90ies have demonstrated that the radial stress (usually due to pressure variations on the pipeline) produces longitudinal cracks. In Europe, the mechanical stress is mainly due to landslides or soil subsidence. In these cases, the localisation of the possible area of stress with the help of geophysics/soil experts engineers is fundamental.
Data of soil characteristics together with pipe-book information (e.g. regarding cold bending of pipe spool bends made in the field during the construction of the pipeline), and many other information such as the weather conditions during the laying of the pipeline, the type of repairs of field joints can be very useful to localize the possible areas which could be affected by this phenomenon.

4.5. - High pH Stress Corrosion Cracking

Quite similarly to the Low pH Stress Corrosion Cracking, the High pH Stress corrosion Cracking is characterised by specific mechanical stress conditions and the low efficiency of Cathodic Protection. One clear distinction between the risk of High pH Stress Corrosion Cracking is high temperature. This kind of corrosion is to be feared mainly at the exit of Compressor Stations (for gas pipelines) or even along the line (for oil lines) with a common characteristic: the high mechanical stress.
The limit level of this stress has been also characterised.

5 - CONCLUSIONS

As it is evident from the above discussion, corrosion phenomena are not only involving the specific knowledge of a CP Engineer, but also implicate many other specialists such as geologists, mechanical engineers, the techniques for the realisation of the pipeline itself, with the many possible conditions which could have determined specific occurrences (presence of coating defects due to bad backfilling or poor sand-bedding before the laying phase of a pipeline, coatings disbonded due to bad application or unfavourable weather conditions, inappropriate use of materials, poor metal cleaning or erroneous coating application.
In a few words, only the real knowledge of a pipeline or a pipeline network allows the CP Engineer to really fight against corrosion phenomena.
A complex DATA BASE or a huge DATA MANAGEMENT SYSTEM or a PIMS (Pipeline Integrity Management System) are not, by themselves, sufficient to guarantee that the pipelines are correctly diagnosed and properly maintained from the Cathodic Protection / Corrosion point of views.
The real point is, as usual, the real knowledge, the experience and the pride to be a Corrosion or better, anti Corrosion and Cathodic Protection Specialist.

REFERENCES

[1] EGIG; European Gas pipeline Incident data Group; 7th EGIG Report 1970-2007;
Doc. N. EGIG 08.TV-B.0502 Dec. 2008.

[2] Report of Study Group 3.4 A Guideline - "Using or Creating Incident Databases for Natural Gas Transmission Pipelines" *23rd World Gas Conference June 1–5, 2006 Amsterdam, The Netherlands*

[3] 23rd World Gas Conference, Amsterdam 2006
PIMS – THE PIPELINE INTEGRITY MANAGEMENT SYSTEM OF VNG - VERBUNDNETZ GAS AG
Main author: Dr. Volker Busack, VNG - Verbundnetz Gas AG, Leipzig, Germany
Co-authors: Ulrich Hoffmann, VNG - Verbundnetz Gas AG, Leipzig, Germany
Dr.-Ing. Manfred Veenker, Dr. Ing. Veenker Ingenieurgesellschaft mbh

[4] Methodologies and Techniques for Corrosion Diagnosis of Buried Pipelines
L. Di Biase – Snam – May 2004, Italy