

CORROSION UNDER DISBONDED COATINGS : DETECTION IMPOSSIBLE ?

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Abstract

Many studies have been performed in the past years on the subject of corrosion under disbonded coatings. One unequivocal conclusion has always been drawn: proper CP is hard or impossible to achieve in the crevice under a disbonded coating, because of the inability of imposed CP systems to pass sufficient protective current to the corroding sites on the pipeline due to the Ohmic drop (IR drop) across the electrolyte within the crevice (shielding effect of the disbonded coating).

Whereas Gas & Oil Companies managing pipelines have serious difficulties in assessing the integrity of pipelines which cannot be inspected by Intelligent Pigs, this topic seems to have been disappeared from the allocation of resources from industry. It is then worth doing efforts in studying and discussing this problem, also to revive the topic at technical/scientific level.

The present paper aims to review the electrochemical characterization of disbonded coatings and to summarize the results of laboratory studies and field experiences on real pipelines performed up to now. If the Polarisation Resistance (R_p) and the Double Layer Capacitance (DLC) could be accurately detected on site along a pipeline by performing specific surveys, these parameters could allow the detection or, at least, give hints on the possible presence of corrosions, even under disbonded coatings.

The comparison of specialised survey results performed on piggable and non piggable pipelines would suggest that this type of detection should be possible, at least at the level of a "Corrosion Likelihood Indication".

Résumé

De nombreuses études ont été réalisées ces dernières années sur le thème de la corrosion sous des revêtements décollés. La conclusion de ces études est sans équivoque : il est difficile, voire impossible, d'obtenir une protection cathodique complète dans la fissure sous un revêtement décollé en raison de l'incapacité des systèmes prescrits de protection cathodique à faire passer un courant protecteur suffisant jusqu'aux points de corrosion sur la canalisation en raison de la chute ohmique (chute IR) à travers l'électrolyte dans la crevasse (phénomène d'écran du revêtement décollé).

Même si des sociétés gazières et pétrolières gérant des canalisations ont beaucoup de mal à évaluer l'intégrité de conduites qui ne peuvent pas être inspectées à l'aide de pistons intelligents, ce thème semble avoir disparu de l'attribution de ressources dans l'industrie. Il est donc utile de faire des efforts pour étudier et discuter de ce problème, afin également de relancer le débat à un niveau technique/scientifique. Le présent article cherche à examiner les caractéristiques électrochimiques des revêtements décollés et à synthétiser les résultats d'études en laboratoires et d'expériences réalisées jusqu'à présent sur le terrain sur de réelles canalisations. Si la Résistance de polarisation (R_p) et la Capacité de Double couche (DLC) pouvaient être détectées avec précision sur le terrain le long d'une canalisation en réalisant des sondages spécifiques, ces paramètres permettraient de détecter ou, au moins, de donner des indices sur la présence éventuelle de corrosion même sous des revêtements décollés.

La comparaison des résultats de travaux spécialisés exécutés sur des canalisations raclables et non raclables suggérerait que ce type of détection serait possible, du moins au niveau d'une "indication de probabilité de corrosion".

Zusammenfassung

In den letzten Jahren wurden zahlreiche Studien zum Thema Korrosion unter abgelösten Beschichtungen durchgeführt. Hierbei wurde stets eine eindeutige Schlussfolgerung gezogen: Ein einwandfreier Korrosionsschutz ist in dem Spalt unter einer abgelösten Beschichtung schwer bzw. unmöglich zu gewährleisten, da die eingesetzten Korrosionsschutz-Systeme keinen ausreichenden Schutzstrom an die von Korrosion betroffenen Stellen in der Rohrleitung leiten können. Dies ist durch den Ohmschen Spannungsabfall (IR-Abfall) innerhalb des Elektrolyts im Spalt bedingt (Abschirmwirkung der abgelösten Beschichtung).

Während Gas- und Ölunternehmen als Betreiber von Pipelines ernste Schwierigkeiten bei der Beurteilung des einwandfreien Zustands der Rohrleitungen haben, die nicht durch intelligente Molche inspiziert werden können, scheint dieses Thema bei der Zuweisung von Ressourcen aus der Industrie keine Rolle mehr zu spielen. So lohnt es sich, die Untersuchung und Diskussion des Problems wiederzubeleben und das Thema auch auf technischer bzw. wissenschaftlicher Ebene wieder ins Gespräch zu bringen.

Die vorliegende Arbeit hat das Ziel, die elektrochemische Charakterisierung abgelöster Beschichtungen zu überprüfen und die Ergebnisse der bisher durchgeführten Laborstudien und Praxiserfahrungen an echten Pipelines zusammenzufassen. Können Polarisierungswiderstand (R_p) und Doppelschichtkapazität (DLC) durch spezielle Untersuchungen vor Ort an einer Pipeline genau festgestellt werden, ermöglichen diese Parameter die Erkennung von oder zumindest Hinweise auf eine mögliche vorhandene Korrosion unter den abgelösten Beschichtungen.

Der Vergleich von Ergebnissen spezieller Untersuchungen an molchbaren bzw. nicht molchbaren Pipelines deutet darauf hin, dass eine derartige Erkennung zumindest als „Indiz einer Korrosionswahrscheinlichkeit“ möglich ist.

1 – Disbonded coatings: origin and causes

One of the most important characteristics of a coating is its adhesion to the metal. It can be useful to distinguish some particular typologies of Disbonded Coatings: these have different origin and quite different consequences.

1.1. Cathodic disbonding

Always originated by an initial low adherence, the phenomenon of Cathodic Disbonding is known as being promoted by high pH values, where the CP current is too high. Recommendations exist to not overcome limits of the ON Potential such as -1.1 Volt vs. Cu/CuSO₄ reference electrode.

In the laboratory, Cathodic Disbonding Tests are usually performed above all as comparative tests to evaluate the performance of a certain type of coating and its application procedures.

The observed corrosion products are dry, brown powdery: obviously they are formed owing to water vapour and oxygen diffusion through the intact coating.

Cathodic disbonding occurs due to a number of reasons:

- Steel surface preparation by acid pickling followed by dipping in hot 3% phosphoric acid solution. In laboratory testing over a 3 month period a phosphated surface gave rise to cathodic disbonding ten times more than blast cleaned or acid pickled steel;
- Cracks have been induced in a bituminous coating at the overlap of the asbestos outer wrap due to the expansion and contraction under alternating wet and dry soil conditions. Despite the coating failures if the CP is effective C.P. system, corrosion damage does not occur.

No pitting or other localised corrosion phenomena have been since now observed under these kind of disbonded coatings. In spite of adhesion loss, high specific coating resistivities were measured on disbonded coatings with values of up to 10¹¹ ohm.m² on single buried pipes and 3*10⁵ ohm.m² on long pipeline sections of PE-coated pipe without any indication of corrosion damage.

As a conclusion, for cathodic disbonding, the following can be affirmed:

At low electrical resistance of the coating, free corrosion cells or cathodic blisters may arise from water migration through the coating which is encouraged by cathodic protection reaction (electro-osmosis). Nevertheless, the maximum theoretical corrosion rate underneath intact coatings due to permeation is very low (less than 1 micron/year) and localised corrosion attack (pitting) will not occur. This is probably due to the fact that the oxygen in the very thin crevice between the metal and the coating is spoiled and corrosion phenomena automatically stops due to oxygen consumption.

So, while literature often quotes alarms on Cathodic Disbonding, these alerts only come from laboratory and research centres.

In the real field, as far as our experience suggests, it may rarely happen, particularly for the coatings having scarce adherence characteristics (scarce surface preparation, bad application).

This phenomenon may lead to the disbondment of large areas of coating even along many km of pipeline. Nevertheless even in these circumstances, the observations in the field have shown that, while the coating is largely disbonded, there is generally no corrosion in the metal underneath the coating, apart a slight superficial oxidation.

1.2. Other types of Disbonded Coatings

Apart the Cathodic Disbonding phenomenon discussed in the previous paragraph, a lack of adherence of a coating to the metal may give rise to subsequent disbondment, above all on large diameters pipelines in clayey, wet soils.

The heavy weight of the filling soil above the pipe may lead the coating to be "pulled down around the pipe", and consequently disbond, typically along the lateral surfaces at 7,00 – 9,00 and 15,00 – 17,00 o'clock.

It has been verified in the field, after excavations, that these disbonded areas can even reach lengths more than 10 m, with an exposed steel area of many m².

Another typical reason for coating disbondment is a bad application of heat shrinkable sleeves or repairs with plastic bands of welded joints during the construction of a pipeline.

This may lead to the disbondment of coating in the lower part of the pipe. In these cases, the area of the steel exposed to the electrolyte is in the order of some m².

1.3. Risks tied with disbonded coatings

Two typical phenomena happen to the metallic surface of a pipeline under disbonded coatings (whichever its origin may be):

- lack of adherence;
- formation of a crevice area;
- water ingress in this area (often increased by the electro-osmotic effect due to the Cathodic Protection current reaction);
- shielding effect due to the coating (high isolating characteristics) towards the CP current which is hindered to reach the metallic surface of the pipeline;
- formation of "corrosion conditions" in the bare steel exposed to the environment (mud, water).

As a matter of fact, while disbonded coatings due to their scarce adherence characteristics rarely result in localised corrosions, coating disbondments due to mechanical reasons as the ones quoted in paragraph 1.2., can lead either to localised corrosions (most frequently microbial corrosion, MIC) or, if the conditions exist, even to Stress Corrosion Cracking.

1.3.1. Microbial corrosion

Microbial corrosion occurs under specific environmental conditions:

- lack of oxygen (this condition can be obtained from previous presence of bacteria which can survive in oxygen containing electrolytes, forming with their metabolic activity an anoxic environment where the Sulphate Reducing Bacteria can proliferate;

Muddy heavy soils can easily give rise to the disbondment of coatings, formation of wrinkles, initiation of microbial corrosion.

Laboratory tests have demonstrated that the activity of bacteria can lead to corrosion rates as high as 0,6 – 0,8 mm/y. When the water table is variable, the corrosion rate can reach values up to 1,5 mm/y and even higher.

1.3.2. Stress Corrosion Cracking in Pipeline Steels

Stress corrosion cracking is a form of “environmentally assisted cracking” where the surrounding environment, the pipe material and the mechanical stress act together to reduce the strength or load carrying capacity of a pipe.

Two types of SCC are known and are referred to as:

- High pH Stress Corrosion Cracking
- Near-neutral pH Stress Corrosion Cracking

1.3.2.1. High pH SCC

High pH SCC occurs in a relatively narrow cathodic potential range (-760 to -790 mV vs. Cu/CuSO₄ reference electrode), in the presence of a carbonate/bicarbonate environment and at a pH greater than 9. High pH SCC is typically experienced downstream of compressor stations (where the product and then the pipe temperature is more elevated) and is associated with disbonded or damaged coatings.

In the cathodic potential range and environment required for high pH SCC, a protective film forms on the metal surface. If the pipe is subjected to a plastic strain, this protective film will crack and create the opportunity for SCC to occur.

Stress corrosion cracks will continue to grow only if the rate of plastic deformation occurs more quickly than the rate at which the protective film re-forms.

The corrosion form of the High pH SCC is intergranular.

1.3.2.2. Near Neutral pH SCC

Although the mechanism of near neutral SCC is not fully understood, it is thought to involve metal dissolution and the ingress of hydrogen into the steel, the hydrogen facilitating crack growth by promoting reduced ductility in the steel. Cracks are probably initiated at corrosion pits on the steel surface containing a localized environment with a pH low enough to produce atomic hydrogen.

The low pH solution is produced by the dissolution of CO₂ in the groundwater. Some of the atomic hydrogen enters the steel, degrading the mechanical properties locally so that cracks can initiate or grow. The plastic stress level necessary to produce cracking may not be related entirely to fracturing the embrittled steel; it may also contribute to rupturing the protective film, allowing hydrogen to reach and penetrate the steel.

The corrosion form of the Near Neutral SCC is transgranular.

For the occurrence of these corrosion phenomena (the so called Near Neutral SCC and the High pH SCC phenomena) appropriate electrochemical and mechanical conditions are necessary, such as:

- lack of adherence;
- shield effect which produces a lack of cathodic protection current, hence a pH near the equilibrium;
- presence of specific electrolyte and pH conditions
- mechanical stress.

If one of these promoting factors is missing, SCC cannot develop.

2 – CP under disbonded coatings

Due to the geometrical characteristics, the bare metal under disbonded coatings cannot be cathodically protected. In fact, the shielding effect does not allow the current to reach these bare surfaces.

It has been demonstrated with laboratory tests, that in the presence of disbonded coatings:

- None or only a very little cathodic protection current can reach the bare steel surface, having this a very high resistance path;
- As a direct consequence, it cannot be detected by traditional electrical surveys (DCVG, CIPS, etc.)

It has been demonstrated that CP can only go 5 to max 10 cm far from the “mouth” of the open holiday.

Nevertheless, the electrolyte (mud, water) can penetrate and get in contact with the bare steel surface, thus corrosion can occur.

With the increase of distance from the open holiday, a high cathodic polarization is required to achieve appropriate CP level at crevice bottom. A potential difference always exists between the open holiday area and inside crevice, reducing the CP effectiveness. The oxygen concentration drops significantly inside crevice no matter if CP is applied.

During field measurements, tests and consequent excavations, some wrinkles in the coating having lengths up to 13 m have been found. This means that while water and mud can slowly penetrate under the disbonded coating and reach the metal, the path for CP current has a very high resistance.

Figure 1 shows the qualitative response in frequency of a pipeline section having a single, open coating fault.

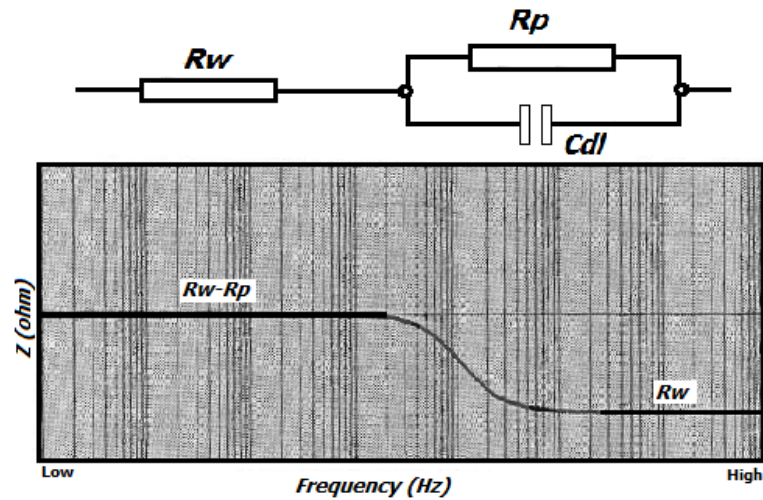


Fig. 1 – Equivalent circuit and relevant Bode diagram for a single, open coating fault

- R_w : Ohmic Resistance of the electrolyte between the reference electrode and the metallic, bare surface;
- R_p : Polarisation Resistance of the metal at the metal/electrolyte interface;
- C_{dl} : Double Layer Capacitance at the metal/electrolyte interface.

If this metallic surface in combined with a surface in corrosion condition under the disbonded coating, the equivalent circuit (Fig. 2 a) and the relevant Bode diagram (Fig. 2 b) are quite more complex.

In this case some supplementary characteristic parameters must be taken into account such as:

- R_{pore} , Resistance of the porosity of the disbonded coating
- C_{coat} , Capacitance of the disbonded coating

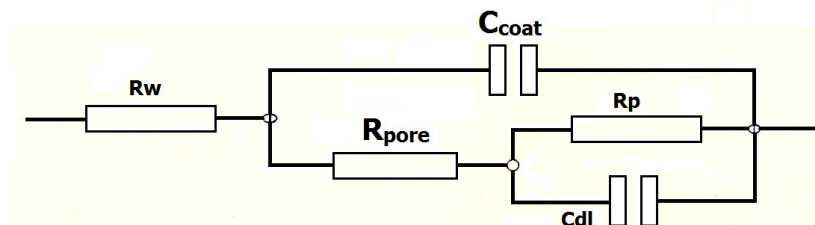


Fig. 2 a – Equivalent circuit for a metallic surface in corrosion conditions under a disbonded coating

Referring to the theoretical Bode diagram of Fig. 2 b, from high to low Frequencies it can be distinguished:

- R_w – *Ohmic resistance* (the IR Drop): the straight line at high frequencies
- R_{pore} – *Ohmic resistance (of the coating)*: the straight line at intermediate frequencies
- R_p – *Polarisation resistance* of the metal from the above said straight line to the low frequencies
- C_{coat} – *Capacitance* of the coating from the high frequency curve which can be calculated by using the mathematical expression ($\omega R_{pore} C_{coat} = 1$)
- Cdl – *Double Layer Capacitance*, which can be calculated from the curve to low frequency, according to the mathematical expression ($\omega R_p Cdl = 1$)

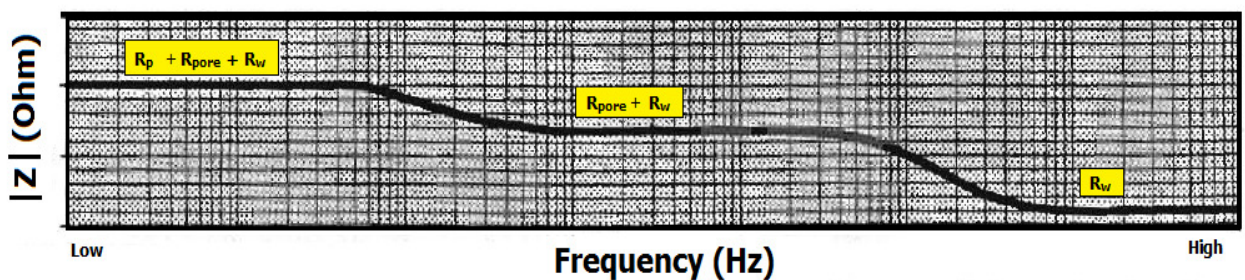


Figure 2 b – Bode diagram for a metallic surface in corrosion conditions under a disbonded coating

According to this model, the localisation of corroding surfaces can be made by comparing the different values of :

R_p : inversely proportional to the corrosion rate

and

Cdl : directly proportional to the surface area in corrosion,

detected at regular intervals along the section of pipeline. The experimental works have been planned after evaluating the feasibility with laboratory tests. Consequently, tests on a real pipeline have been performed, by adapting the laboratory devices and instrumentation to the field conditions.

3. – Field measurements

Pipelines suffering from disbonded coatings are to be considered in "corrosion conditions". The graph of the Figure 3 has been obtained by forcing into the pipe a CP current 3 times more than the "normal" CP current usually considered sufficient to cathodically protect the pipeline.

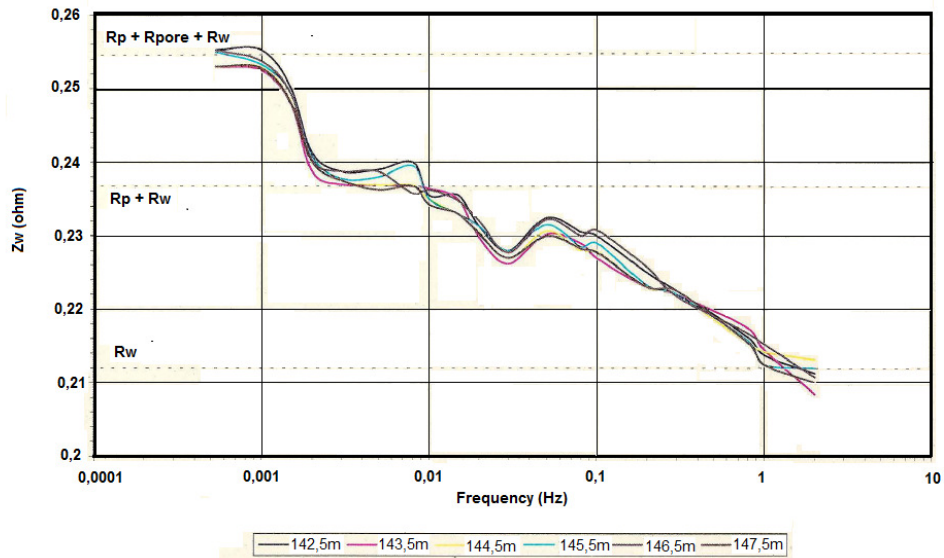


Fig. 3 - Bode Plots obtained over the line from 142,5 to 147,5 m.

By performing these type of measurements over a 60 m of pipeline, the graph of Figure 4 has been obtained.

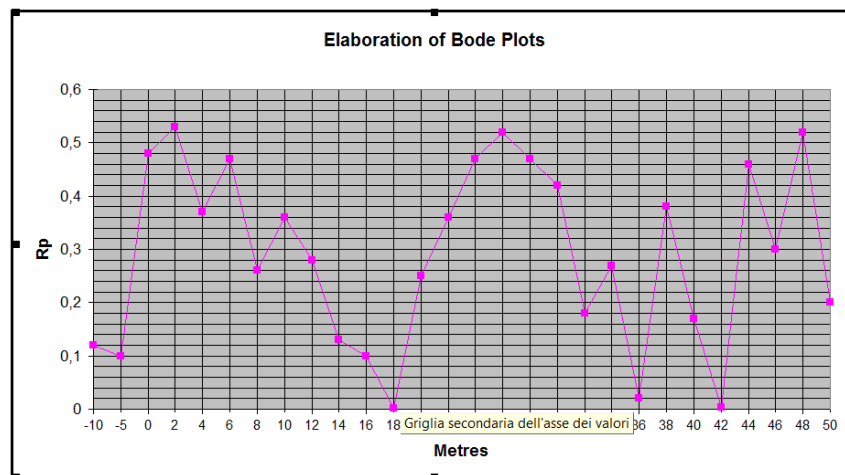


Fig. 4 – Field results obtained over a section of pipeline length 60 m by calculation of R_p

When excavating, 3 corrosions under the disbonded coating were found at the distances 18, 36 and 42 m along this pipe. The above measurements demonstrate the following:

- Where a path exist between the metallic surface and the electrolyte, it is possible to detect sufficient signals by above soil measurements by "pushing" more current than the "normal" Cathodic Protection current;
- It is possible to detect the positions where the electrolyte is in contact with an area of disbonded coating, thus allowing its detection;
- The Bode Diagrams detected along the line are able to give information on the existence of disbonded coatings with corrosion underneath.

It is possible, in principle, to detect corrosions under disbonded coatings, by specialised cathodic protection surveys, with the following limitations:

- Due to the fact that the various components of the circuit (Resistance, Capacitance) are in parallel, the differences among the signals over the line are very small;
- Long time consuming and laborious measurements in the field and complex computerised elaborations are necessary;
- The technique only gives a qualitative response to whether corrosion conditions exist in the metallic areas under the disbonded coating in the section of the survey;
- It's rather impossible to use this technique in stray current interfered areas.

5 – Conclusions

Disbonded coatings in a buried pipeline often gives rise, in the long term, to microbial corrosion. This is due to the formation of an area of bare metal which is in contact with the electrolyte, but cannot be cathodically protected, due to the shielding effect; the coating itself acts as a barrier which hinders cathodic protection current to reach these bare surfaces.

In the long run aerobic bacteria can grow that eventually develop anaerobic conditions where anaerobic bacteria will attack the metal in their metabolic mechanism.

It has been demonstrated by laboratory and field measurements that the IR drop in the so-called micro-channels is very high, but a little current reaches in any case these surfaces in the mouth of the crevices. The current is not enough to protect cathodically the entire disbonded metallic surface area, but allows to make measurements.

By applying low frequency currents, the Bode Plots have demonstrated to be able to allow the detection of areas under these disbonded coatings (which are characterised by a high/very high capacitance). While the technique is valid, the operability of the technique is quite difficult and rather complex. The method can be applied only where there are no electrical disturbances, by using the sampling-and-hold acquisition methodology so that contemporaneous measurements can be performed in the same moment in different positions on a sufficiently long section of pipeline (e.g. every 2 m on a section of 200 m). The method can only give a qualitative response to whether a corrosive phenomenon is in course in some positions of the section considered. These positions could not correspond to the real corrosion position, but to the micro-channel connecting the bare surface of the pipeline to the electrolyte. A quite long time consuming process for both the field measurement and the elaboration of data is necessary. Then, the technique is also applicable in the field, but not feasible at industrial level. Further developments are needed in order to use a larger number of reference electrodes and appropriate sampling-and-hold automatic acquisition devices.

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