Shielding coatings? They Should!

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Abstract:

Coatings are applied on buried and immersed metal pipelines in order to minimize the risk of corrosion. Since perfect coatings do not exist, cathodic protection is often installed to act as a backup for coating imperfections.

However, in some situations cathodic protection is unable to provide this backup, especially with initially unbound or disbonded coatings that have high electrical insulation resistance like polymeric types.

In general, cathodic protection is only effective when the current density at the steel substrate meets certain requirements, and this is not different for areas where disbondment of coating has occurred.

Literature studies and experiments revealed that the void dimensions and conductivity of the soil-electrolyte are critical parameters that define whether or not cathodic protection is effective underneath disbonded coatings.

Introduction

Oil and gas transport pipelines are mostly constructed of carbon steel, which mainly consists of iron. This is by far the favourite material for those pipelines, because it has many advantages over other types of materials. Carbon steel however, is susceptible to several types of corrosion. The most common type is the electrochemical reaction of iron with oxygen and water that forms rust (1). Another type is Microbiological Influenced Corrosion (MIC) under anaerobic conditions, as a result of the presence and metabolism of sulphate reducing bacteria (SRB) and fermentative acid-producing bacteria (APB), which are especially abundant in soil (2).

To minimize the risk of corrosion the steel surface is provided with a coating that forms an effective barrier against oxygen and water. Damage to pipe coating is almost unavoidable during transportation and construction of the pipeline due to the often heavy loads involved, machinery and equipment used, and - sometimes - bad handling and improper installation practices in the field. Furthermore, during operation of a pipeline other damages may occur such as shear of the coating caused by pipe movements due to temperature fluctuations, loss of essential properties due to ageing (like adhesion, permeability), and many more (3).

Breaks or holidays in pipe coatings may expose the pipe to possible corrosion, since after a pipe has been installed underground, the surrounding earth will be more or less moisture-bearing and it constitutes an effective electrolyte, which will allow the transportation of ions. This is where the cathodic protection systems comes into action; it acts like a back-up for coating imperfections.

Initially unbound coatings and disbonded coatings

Initially unbound coatings mainly occur due to improper installation practices. With several types of coatings such as polymeric tapes and heat shrinkable sleeves, an overlap of the coating is created on the parent plant coating and/or on the applied tape/sleeve itself. Plant coatings are often made of materials with high electrical resistance, and all types of polymeric tapes and heat shrinkable sleeves have high electrical resistance as well. Improper application can leave a void between the layers of coating that fills with water and soil from its environment.

Coating disbondment can have several causes, e.g.:

- Degradation of adhesives due to ageing caused by environmental and operational influences like e.g. exposure to aggressive substances present in soil, elevated operational temperatures, microbiological breakdown of components present in adhesives, and more.
- Break of the initial bond by excessive mechanical forces like impacts and shear.
- Extension of disbondment by active cathodic protection, called cathodic disbondment.

Initially unbound and disbonded coatings can appear in many different forms. They can coarsely be divided in two separate types of appearance:

- those having an opening that is oriented perpendicular to the pipe and having a short pathway from steel to environment. This particularly occurs with coating damages caused by mechanical impacts and indentation.
- those having a crevice-like opening that is oriented along the axis of the pipe and having a relatively long pathway from steel to environment. This often occurs with improperly installed or degraded coatings having an overlap onto plant coatings and/or onto itself. The pathway is electrically insulated from the environment by electrical insulating properties of the surrounding polymeric materials. Since the void is filled with an electrolyte from the environment, an electrically conductive channel is created from environment to the steel surface.

Cathodic protection – how it works

Cathodic protection is a method in which the potential of a system is forced towards less corrosive values. It is accomplished by applying current from an external electrical power source (impressed current) or sometimes by using a sacrificial anode. The generally accepted theory is that the rates of the electrochemical corrosion reactions of iron are reduced or even prevented by shifting the potential to less corrosive values. Recent investigations done by Büchler (4) however, have indicated that maintaining a high pH and the formation of a passive film at the steel surface is most likely the predominant factor in suppression of the corrosion reactions. Sulphate Reducing Bacteria however, are known to have high tolerance toward alkalinity.

Minimum requirements for the effectiveness of cathodic protection have been established through several investigations. They are depending on the circumstances encountered at the surface to be protected.

> Büchler (4), (5) reported that a potential more negative than -1000 mV vs CSE is required, combined with a minimum current density of 1 mA/m² in case of convection blocking. This is a situation where wash away of the passive film and the electrolyte with high pH from the steel surface is kept to a minimum by blocking action of the surrounding materials such as disbonded coatings.
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> Offshore structures have different requirements as for instance stated in DNV-RP-B401 (6) . A potential of -900…-1050 mV vs Ag/AgCl/Seawater is required, while recommended current densities vary from 70 – 120 mA/m² depending on climate and immersion depth. In such situations there is hardly any convection blocking and a passivation film cannot remain on the surface due to wash off by seawater currents.

CP current distribution under disbonded coatings

Cathodic protection may not work underneath initially unbound or disbonded coatings. Many coatings used nowadays consist of electrical insulating materials – such as polyolefins – and are therefore not able to conduct cathodic protection currents needed. Spreading of CP-current from the coating voids underneath the disbonded coating may be insufficient to effectively protect steel against corrosion.

Many investigations have been done on effectiveness of cathodic protection underneath disbonded coatings.

> Peterson et al (7) have studied cathodic polarization and pH changes in Type 304 stainless steel crevices. In their experiments they simulated a coating that had disbonded from steel having an opening of 3” x 2 to 3 mil, and using a 0.6 M NaCl solution. They reported that crevices with a distance to crevice opening ratio of 12.000:1 can be polarized and that the pH shifted in the alkaline direction.
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> Fessler et al (8) has performed theoretical and experimental study on cathodic protection levels under disbonded coatings. In their experiments they simulated a coating that had disbonded from steel having an opening of 2.5 cm, the simulated disbonded coating being separated from the steel using a thin Teflon sheet, and using a 1N sodium carbonate / -bicarbonate solution as electrolyte. They reported that the potential at the steel holiday have important effects on the potential gradient, and that holiday potentials more negative than that required form hydrogen bubbles that can cause difficulty in controlling the potential under disbonded coatings. Furthermore they found that the potential gradients are surprisingly insensitive to the shape of the crevice.
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> Chin et al (9) have studied current and potential distributions inside the crevice of asimulated disbonded coating with a holiday during cathodic protection. In their experiments they simulated a coating that had disbonded from steel, having a centred initial holiday of 5 mm, a circular crevice having a diameter of 95 mm and a distance between coating and steel of 0.8 mm. Different NaCl solutions were used varying in concentrations between 0.001M and 0.6M. Depending upon NaCl concentrations, the local current density on steel exhibited a 100-fold to 1000-fold decrease from that at the holiday opening.
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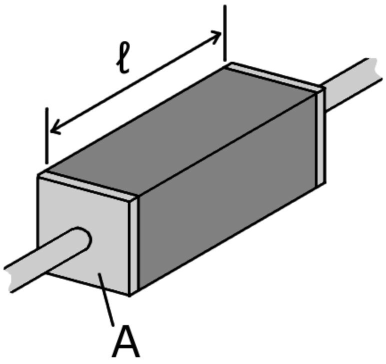
> Li et al (10) demonstrated that it was possible to predict and evaluate the CP status under a sleeve coating that had disbonded from steel at girth welds using multiple quadratic regression analysis by considering the results of numerical modelling and the overprotection problems. From their study they concluded that the IR drop of soil and the specific geometry of the crevice in this study make it very hard for the CP current to penetrate effectively into the crevice under the disbonded sleeve in a given condition. They also concluded that the centre of the crevice could be cathodically protected at a high conductivity electrolyte, whereas at a low conductivity condition, sufficient CP could not be achieved at the centre region of the crevice.

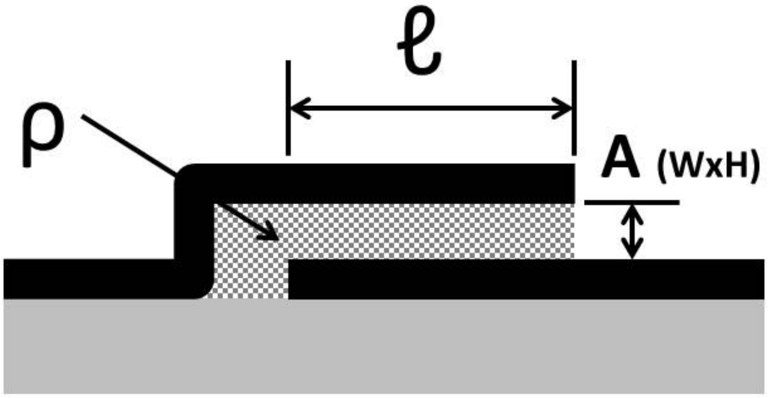
Xu et al (11) studied corrosion behaviour of cathodically protected carbon steel under a disbonded coating in the presence of Sulphate Reducing Bacteria. They found that the steel is not effectively protected by Cathodic Protection in the presence of SRB in the deeper crevice, in spite of the pH being increased to values above 9.

All of the above studies considered a coating that had disbonded from the steel surface directly. With crevice-like disbondments, having an relatively long and electrically conductive channel from steel to environment, an additional resistor is introduced in the electrical circuit of CP. The conductivity of the electrolyte and the dimension of the opening determine the electrical resistance of this pathway.



$$R = \rho \frac{\ell}{A}$$

R = Resistance (Ω)
ρ = Resistivity of electrolyte (Ω.m)
ℓ = Length (m)
A = Cross-sectional area (m^2)

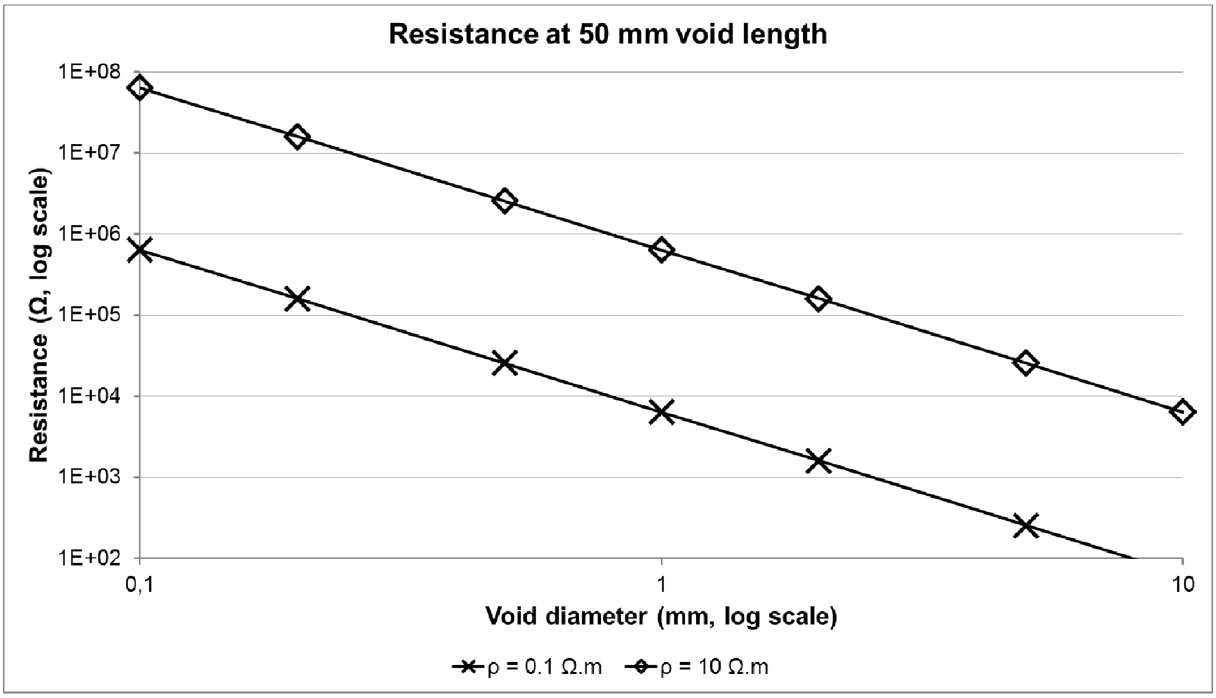


Schematic representation of disbonded coating

Under normal circumstances, a CP power supply is adjusted according to variables measured at the pipe location. E.g. soil conductivity, off-potential, and current density are considered when adjusting CP power supply. The settings of the CP power supply do not account for situations as depicted above.

The resistance of the filled crevice determines whether the requirements for polarization potential and current density at the bare steel surface under a disbonded coating are fulfilled. At relatively small opening dimensions and/or at high resistivity of the electrolyte, the requirements will probably not be met. Furthermore, small crevice dimensions will hinder the transport of electrolyte inwards and pH might therefore not increase.

The graph below shows the calculated resistance for a typical situation with overlapping polymeric materials. The resistance is plotted versus void dimensions (opening assumed to have circular shape) at various electrolyte conductivities.



Non-shielding coatings have been introduced as a possible solution to overcome corrosion under disbonded coatings One type of such coating consists of a tape comprising an relatively thick electrically insulating butyl rubber adhesive compound provided with a woven polymeric mesh backing. Such tapes are wrapped with an overlap onto itself, leaving voids between the 2 layers of tape due to the meshed backing. These void will then be filled with soil and/or electrolyte, and it is claimed that this will allow cathodic currents to effectively pass under the coating. The effectiveness of this approach is doubtful for the following reasons:

- It is not clear whether sufficient cathodic protection current can reach the steel surface at high soil resistance values.
- Void dimensions may decrease due to soil pressure, leading to an increase of overall void resistance.
- According to the study of Xu et al (11) steel is not effectively protected by Cathodic Protection in the presence of SRB.

A totally different approach would be to apply a coating that completely seals the bare steel area from its environment. Such coating should then be tolerant toward minor application failures, and should have a good long term performance. It should be virtually inert to all kinds of influences that would cause coating deterioration. By preventing water from reaching the bare steel area, the electrochemical corrosion reaction of iron to form rust cannot occur. Moreover, Microbiological Influenced Corrosion cannot develop because the bacteria involved in this type of corrosion cannot develop when water is absent. Coatings based on Polyisobutene (non-crystalline low-viscosity polyolefin) (12) have proved to fulfil these demands.

Literature

(1) Pierre R. Roberge; “Corrosion Basics - An Introduction (2nd ed.)”. Houston, Texas, USA : NACE International (2006).

(2) S.Y. Li, Y.G. Kim, K.S. Jeon, Y.T. Kho, and T. Kang; “Microbiologically Influenced Corrosion of Carbon Steel Exposed to Anaerobic Soil”; NACE Corrosion Journal Vol. 57 No. 9 (2001)

(3) Dr. Colin Argent et al.; “Macaw's Pipeline defects”. Newcastle upon Tyne, UK : Yellow Pencil Marketing Co. Ltd., ISBN 0-9544295-0-8 (2003)

(4) Markus Büchler, Swiss Society for Corrosion Protection (SGK), Zurich, Switzerland – Publication in NACE Materials Performance Vol. 54 No. 1 : NACE International (2015)

(5) Markus Büchler; “The IR-free potential: Field data comparison”, Swiss Society for Corrosion Protection (SGK), Zurich, Switzerland (2014)

(6) Recommended Practice DNV-RP-B401(2010); ”Cathodic Protection Design”, Det Norske Veritas

(7) M.H. Peterson and T.J. Lennox; “A study of cathodic polarization and pH changes in metal crevices”: Nace Corrosion Journal, Vol. 29, No. 10 (1973)

(8) R.R. Fessler, A.J. Markworth, and R.N. Parkins; “Cathodic protection levels under disbonded coatings”, Nace Corrosion Journal, Vol. 39, No. 1 (1983)

(9) D.-T. Chin and G.M. Sabde; “Current Distribution and Electrochemical Environment in a Cathodically Protected Crevice”, Nace Corrosion Journal, Vol. 55, No. 3 (1999)

(10) S.Y. Li, Y.G. Kim, Y.T. Kho, and T. Kang; “Statistical Approach to Corrosion under Disbonded Coating on Cathodically Protected Line Pipe Steel”, Nace Corrosion Journal, Vol. 60, No. 11 (2004)

(11) Jin Xu, Cheng Sun, Maocheng Yan, and Fuhui Wang; “Corrosion of Carbon Steel Q235 in a Crevice Under a Simulated Disbonded Coating”, Nace Corrosion Journal, Vol. 70, No. 7 (2014)

(12) ISO 21809-3; “Petroleum and natural gas industries – External coatings for buried or submerged pipelines used in pipeline transportation systems – Field joint coatings” - Amendment 1 (2011).