COATING CONDUCTANCE – FRIEND or FOE
- be careful what you specify

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Abstract

The “quality” of a pipeline coating has a direct bearing on the cathodic protection requirements for a buried pipeline. Quality can be defined in many ways, and is a combination of the intrinsic properties of the coating material itself, the characteristics of the applied coating, the extent of mechanical damage to the coating during pipeline installation and the coating age/degradation properties.

NACE Standard TM0102-2002[1] offers a definition of coating quality in terms of the electrical conductance characteristics of an installed pipeline, and provides a standard test method for measurement.

The values given in TM0102 bear little resemblance to typical properties of coatings reported in Baeckman & Schwenk[2] on page 159. The concept of normalising the coating conductance presented in TM0102 further complicates the issue and can lead to anomalous conclusions.

Project specifications may use the concepts given in TM0102 to ensure that an installed pipeline meets the design parameters that have been set. For example, a value of 100μS/m^2 has been used as the maximum allowable conductance for a newly installed pipeline. However, the question arises whether the value should be related to soil resistivity as suggested in the concept of “normalised” specific conductance.

Using data from an actual pipeline construction project, this paper will illustrate the pitfalls of applying a parameter to an acceptance criterion without fully understanding the principles of that parameter and the consequences of the specification requirement.

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INTRODUCTION

There has been a steady drive over the last few decades to improve the "quality" of external coatings used for corrosion protection of buried pipelines. As many countries have a statutory requirement for cathodic protection of these same pipelines, one of the measures of "quality" has been the current demand to achieve the level of polarisation required by the relevant codes. If one considers the electrical characteristic of the cathodic protection process, protection can be represented by a potential developed across the pipeline/soil interface. This potential is governed by an ohmic[a] relationship between resistance (or conductance) and current. The effective resistance of the applied coating is governed by the characteristics of the coating itself, the application parameters, the extent of mechanical damage during construction and the properties of the soil in which the pipeline is buried.

It is therefore no surprise that electrical resistance has been used as a measure of coating quality, as the greater the resistance, the less current is required of the cathodic protection system.

Electrical resistance and electrical conductance are the inverse of one another and follow the same electrical laws. This discussion will refer to both conductance and resistance, whichever is simpler to relate to the surface area of the pipeline in contact with the soil.

Measurement of coating conductance is covered in NACE TM 0102[1]. This standard test method sets out the procedures for measuring the effective conductance of a coating on a buried pipeline. The measurement techniques are not the subject of this discussion. In order to eliminate the geometric considerations from the equation, the term specific conductance is used which has the units S/m^2.

NACE TM 0102 further introduces the concept of normalised specific conductance which endeavours to compensate for the effect of soil resistivity. In this process the contact resistance (or conductance) is linearly related to the soil resistivity as can be seen from all the standard anode resistance formulae[2].

The specifier of a pipeline coating can therefore be forgiven for setting out a pipeline coating requirement that is independent of both pipeline geometry and soil conditions, as both of these are often unknowns at the time of compiling a project specification. This is done in the belief that defining a maximum normalised specific coating conductance value will ensure that the CP system will have adequate capacity to provide protection to the pipeline.

Unfortunately this approach has some unintended consequences:

Note [a] For the purposes of this discussion, the electrochemical and capacitive characteristic of the pipe/soil interface are not considered.

CASE STUDY

Reference to NACE TM 0102 reveals the following table of parameters for pipeline coatings:

TABLE 1: Table of Specific Coating Conductance vs. Coating Quality for 10 Ω-m Soil

Coating Quality	Normalized Specific Conductance Range ($\mu S/m^2$)
Excellent	< 100
Good	101 to 500
Fair	501 to 2,000
Poor	> 2,000

Our naïve specifier, having diligently referred to the NACE standard, wishes to ensure that the pipeline coating is of the highest possible quality, therefore includes the following performance requirement in the project specification:

> "The applied coating shall have a maximum normalised specific coating conductance of 100μS/m2 when measured in accordance with NACE TM 0102."

The first test results from the pipeline revealed the following results:

TABLE 2: NORMALISED COATING CONDUCTANCE G' TO 10Ωm SOIL RESISTIVITY FROM SITE DATA

Pipeline section	Resistivity ρ (Ωm)	Specific Conductance G ($\mu S/m^2$)	Normalised Specific Conductance G' ($\mu S/m^2$)	Coating Quality (from TM 0102)
500m 1500m	935	3.9	365	Good
1500m 2500m	977	5.0	488	Good
2500m 3500m	1006	4.9	493	Good
3500m 4000m	1079	3.8	410	Good
4000m 5000m	767	5.3	406	Good
Average	**940**	**4.7**	**442**	**Good**

Referring to the NACE classification, we see that the pipeline only just complies with the "Good" classification, in spite of the fact that it only requires $1.4\mu A/m^2$ to achieve cathodic protection (based on 300mV polarisation), and, more importantly from a contractual viewpoint, it does not comply with the project coating specification requirement.

RESISTANCE CONSIDERATIONS

The contact resistance of a square meter of pipe surface can be approximated by the resistance of a flat plate at grade level[2]. This resistance is given by the formula:

$$R_s = \rho/2d$$

Where

R_s = contact resistance (Ω)

ρ = soil resistivity (Ωm)

d = equivalent diameter of surface (m)

The contact resistance R_s of one square meter of pipe surface is therefore 416Ω in 940Ωm soil. At 10Ωm, it would be 4.4Ω

However, this calculation applies to a conductive surface in contact with the soil, and we have a coating on the surface of the pipe with a high dielectric characteristic. The resistance of the coating is given by the formula:

$$R_c = \rho \ell / A$$

Where

R_c = resistance of 1m^2 of coating (Ω)
ρ = coating resistivity (Ωm)
ℓ = coating thickness (m)
A = surface area (m^2)

For a typical pipeline coating[2] with practical resistivity 10^8 Ωm and thickness of 4mm, this gives a theoretical resistance value for R_c of 354kΩ for one square meter of surface area.

The total contact resistance R_T of one square meter of surface in 940Ωm soil is therefore the sum of these two resistances which are in series, i.e.

$$\begin{aligned} R_T &= R_s + R_c \\ &= 354\text{k}\Omega + 416\Omega \\ &= 354.4\text{k}\Omega \end{aligned}$$

Note that the contact resistance only contributes a minute percentage of the total resistance.

The coating resistance remains constant irrespective of the soil resistivity. If we follow the principle given in TM 0102 and calculate the equivalent resistance based on the **normalised** specific conductance using the site data from Table 2, this would be

$$\begin{aligned} R' &= 1/G' \\ &= 1/442 \\ &= 2.2\text{k}\Omega \end{aligned}$$

This value is significantly less than the resistance of the coating itself, which is impossible. The actual resistance in 10Ωm soil would be 345.004kΩ

The total resistance based on the measured specific coating conductance from Table 2 would be:

$$\begin{aligned} R_T &= 1/G \\ &= 1/4.7 \\ &= 213\text{k}\Omega \end{aligned}$$

This is in line with the theoretical value of 354.4kΩ.

DISCUSSION – WHAT SHOULD WE SPECIFY?

The above example illustrates that the contact resistance, which is the only factor related to resistivity of the soil, is insignificant for pipeline coatings with high electrical resistance characteristics. Thus the principle of characterising high resistance coatings based on normalised specific conductance is fundamentally flawed. However, pipeline coatings are seldom free of defects, and their electrical resistance characteristics deteriorate with time[2]. So at what stage does the contact resistance become a significant factor in the equation?

If we consider that the contribution of the contact resistance to the total resistance of the pipeline to soil (staying with our 1 square meter area) will increase as the coating either degrades or experiences mechanical damage, it is easy to see that the effective specific conductance of the system will increase. This is illustrated in Figure 1

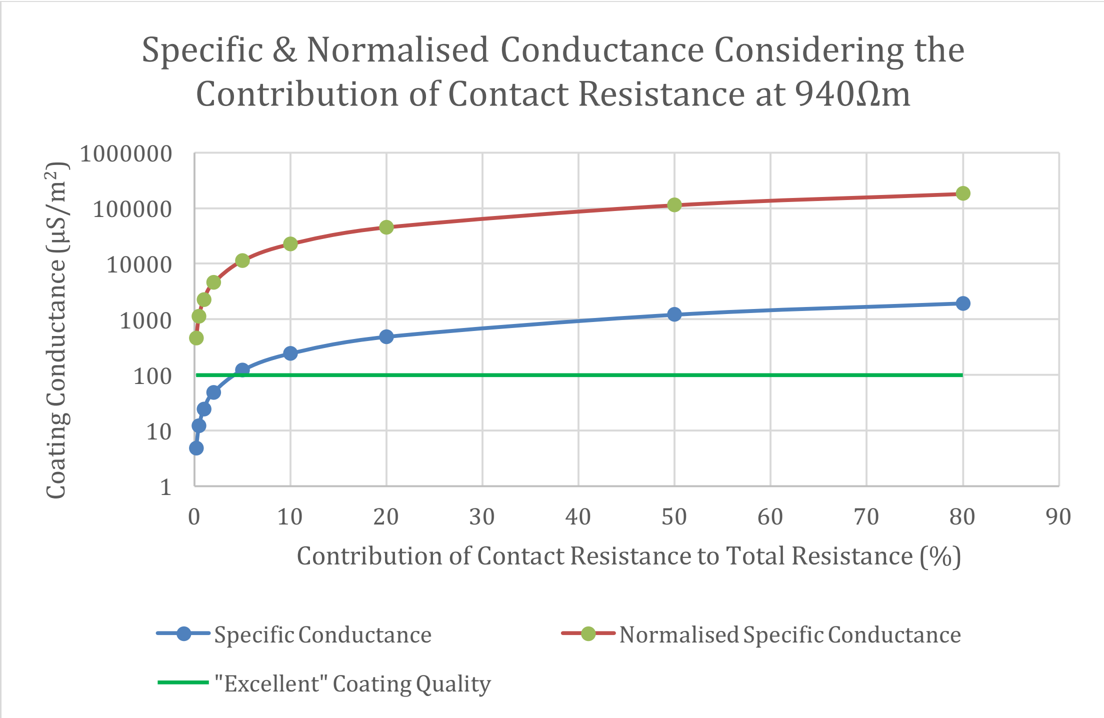

Figure 1: Specific & Normalised Conductance Considering the Contribution of Contact Resistance at 940Ωm

At lower soil resistivities, the contribution of the contact resistance will have to be correspondingly lower in order to maintain maximum allowable specific conductance values.

Aged, damage free pipeline coatings[2] have been found to have specific resistivities in excess of 10^4 Ωm^2, i.e. specific conductance < $100\mu S/m^2$. This equates to the "excellent" category in terms of the NACE TM 0102 characterisation for soil resistivity of 10Ωm. This indicates that coating degradation, defects and/or damage are the primary cause of increased coating conductance.

It has been shown that bareness factor (% bare area) can be related to effective coating conductance for FBE coatings[3]. In terms of the TM 0102 definitions, an excellent coating has a bareness factor of <0.006%, whilst a poor coating exceeds 0.1% bare area. This latter would equate to 1 in 10 field joints not being coated.

This illustrates the importance of controlling mechanical damage to pipeline coatings during construction.

CONCLUSION

- Based on the above example and discussion, there is evidence to suggest that use of **normalised** specific coating conductance as set out in NACE TM 0102 leads to unrealistic classification of pipeline coatings with high electrical resistance.
- Inappropriate specification requirements can lead to unnecessary contractual compliance issues.
- Coating performance specifications should be based on the use of specific coating conductance for new pipeline construction.
- Control of mechanical damage during construction has a significant effect on overall coating conductance characteristics.
- Many pipeline coatings (even aged bitumen)[2] without significant mechanical damage exhibit specific resistance $>10^4\ \Omega m^2$, and therefore fall into the category of "excellent"

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