EMPIRICAL POTENTIAL-DEPENDENT CORROSION RATE FOR UNDERGROUND PIPELINES

Roelof Coster
DNV GL
Energieweg 17
9743 AN Groningen
The Netherlands
Roelof.Coster@dnvgl.com
+31 50 700 9777

ABSTRACT

Variations over time of the pipe to soil potential are expected to cause variations in the corrosion rate of underground pipelines. It is likely that external corrosion defects grow faster during periods when the potential is less negative. This paper will present a model for this potential-dependent corrosion rate.

The model is fully empirical, based entirely on data from pipelines of Gasunie Transport Services in the Netherlands. It follows from matching the depths of external corrosion defects, as determined by pigrun inspections, to the history of ON potentials that the corresponding pipeline section has experienced over its entire lifetime until the moment of inspection.

The resulting model is applicable to forecast future corrosion growth based on ON potentials, as well as to estimate the maximum corrosion depth on not yet inspected pipelines in the Netherlands of the same operator.

1 INTRODUCTION

By way of introduction, the following graphs display the ON potential that four pipeline sections experienced over their lifetimes (top) and the peak wall loss of external corrosion defects in those same sections (bottom). This article will discuss how the history of ON potentials that a pipeline section has experienced over its lifetime can be used to predict its peak wall loss, that is, how the top graph explains the bottom graph.

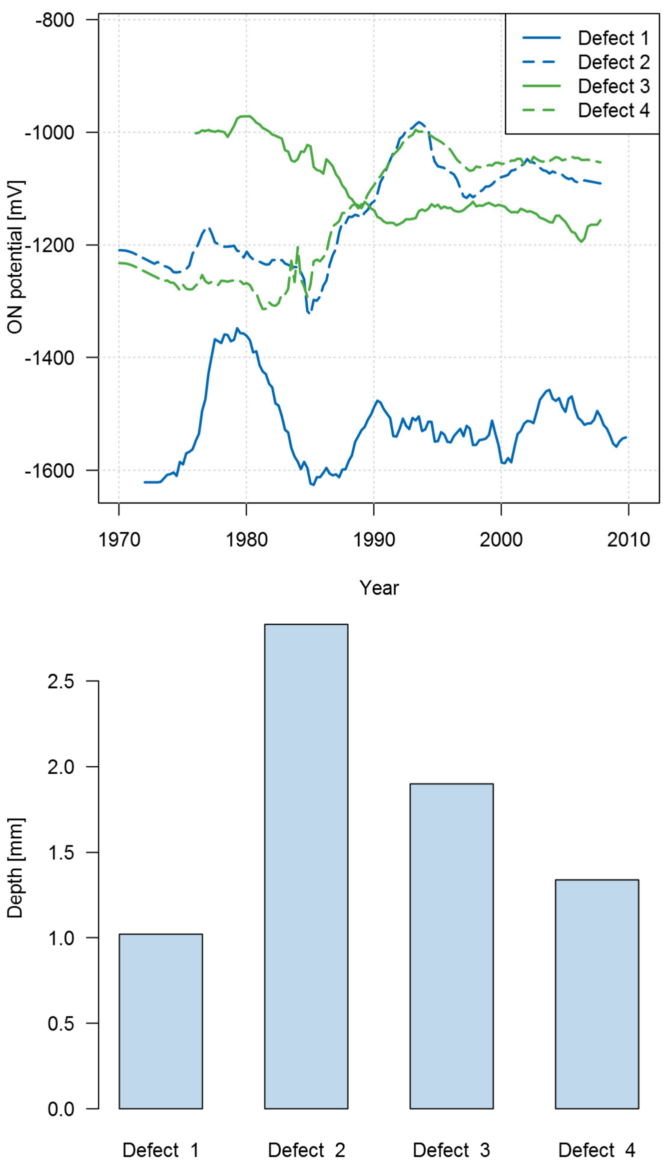

Figure 1: ON potentials (top) and corrosion depths (bottom) of four pipeline sections.

The data that are displayed in the graph are a sample from real data from the Gasunie Transport Services (GTS) pipeline network in the Netherlands. The corrosion depths were reported by pigruns and the history of ON potentials is based on the logs of the cathodic protection measurements that were performed from the early 1970's onwards. All the conclusions in this article are based on these real data.

The cathodic protection logs were taken at irregular intervals and at irregularly spaced test posts. The full history of the ON potentials of each pipeline section was calculated based on these irregular data. The method to do this was discussed in detail in an article that was presented at CEOCOR 2016 [1].

Most pipelines in the scope of the study were constructed after 1970. For these, the entire history of ON potentials is available. For the pipelines constructed before 1970, some years of their history are missing.

2 CORROSION RATE BASED ON DEFECT DEPTH

The aim of this article is to investigate how the pipe to soil potential determines the corrosion rate. The corrosion rate of pipelines in the field is not observed. What is observed, is the depth that the defects attained at the time of inspection. The observed depth of an external corrosion defect[1] is related to its time-varying corrosion rate by the following equation:

$$D_i(T) = \int_{B_i}^{T} s_i(t)dt \qquad (1)$$

D_i: Depth of the i'th defect [mm].

B_i: Time at which the defect initiated [year].

T: Time of inspection [year].

$s_i(t)$: Corrosion rate of the i'th defect at time t [mm/year].

The model that will be explored is based on the assumption that the corrosion rate varies as a result of the variations in pipe to soil potential. This can be expressed by the following equation:

$$s_i(t) = r_i(U_i(t)) \qquad (2)$$

$s_i(t)$: Corrosion rate of the i'th defect at time t [mm/year].

$r_i(x)$: Corrosion rate [mm/year] of this defect at a pipe to soil potential of x mV.

$U_i(t)$: Pipe to soil potential [mV] of this defect at time t.

Ideally, the pipe to soil potential in equation (2) should be the IR-free potential. However, the research is based on actual registered data from the GTS network. No data are available of IR-free potentials for each pipeline over its lifetime. On the other hand, for each pipeline section

[1] For the remainder of this article, the term 'defect' will be used for 'external corrosion defect'.

there is available a calculated history of the ON potential that the section experienced [1]. Since the ON potential is related to the IR-free potential, the ON potential will be used in equation (2) as a good approximation.

The approximation (2) can be inserted into equation (1) to arrive at the model in equation (3). However, one more simplification is needed first. The integral in equation (1) starts at the time of initiation of the defect, which is unknown. The year of construction is used instead.

$$D_i(T) = \int_{B_i}^{T} r_i(E_i(t))dt \qquad (3)$$

D_i: Depth of the i'th defect [mm].

B_i: Year of construction of the corresponding pipeline segment.

T: Time of inspection [year].

$E_i(t)$: ON potential [mV] of the corresponding pipeline section at time t.

$r_i(x)$: Corrosion rate [mm/year] of the i'th defect at an ON potential of x mV.

Equation (3) is a physical corrosion model that matches the defect depths, known from pigrun inspections, to the history of ON potentials, which is known approximately (see reference [1]). The link between the two is the potential-dependent corrosion rate $r_i(x)$. Finding this is the goal of the research.

To conclude this section, two technical requirements need to be specified that any model for potential-dependent corrosion rate needs to satisfy.

1. The corrosion rate must be nonnegative, because defects cannot grow smaller.
2. The curves must be nondecreasing: the corrosion rate at more positive potential cannot be lower than at more negative potential.

3 EMPIRICAL CORROSION MODEL

In this section, the model for the potential-dependent corrosion rate is presented. This model follows as the statistical best match between equation (3) and the data set of all defects.

The following graph displays the result. The interpretation of the graph is discussed in the remainder of the section.

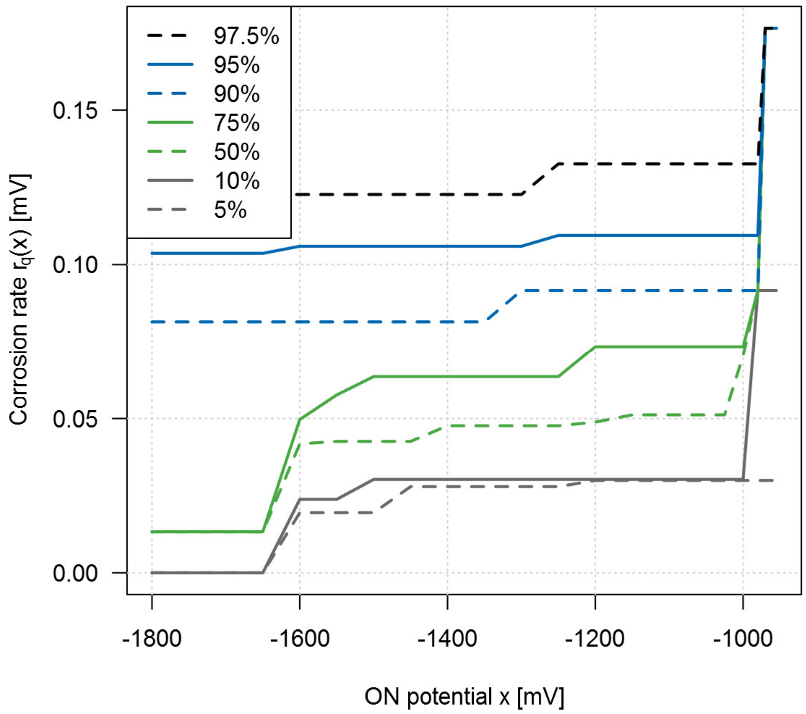

Figure 2: Resulting empirical potential-dependent corrosion rates $r_q(x)$.

The interpretation of the graph is as follows.

An empirical corrosion model is a curve $r(x)$ that gives the best possible match between equation (3) and the observed data. For this, first a definition is needed for what is meant by 'best possible'.

The definition will be based on quantiles. In what follows, the value q is a quantile, that is, a number between 0 and 1. For each chosen q, a curve $r_q(x)$ is calculated that satisfies the following equation:

$$P\left(D \leq \int_B^T r_q(E(t))dt\right) = q \qquad (4)$$

D: Depth of a defect [mm].

B: Year of construction of the corresponding pipeline segment.

T: Time of inspection [year].

$E(t)$: ON potential [mV] of the corresponding pipeline section at time t.

$r_q(x)$: Calculated corrosion rate [mm/year] at an ON potential of x mV.

q: Chosen number between 0 and 1.

Also, each curve $r_q(x)$ must satisfy the two requirements at the end of the previous section (be nonnegative and nondecreasing) to be a realistic model for the corrosion rate.

Each choice of q results in its own curve $r_q(x)$. For example, one may choose q=0.1 (i.e. 10 percent). To this value corresponds the curve $r_{10\%}(x)$. This curve can be used to predict the depth of each defect by filling it into equation (3), along with the history of ON potentials that the pipeline section experienced. If this is done, 10 percent of the observed defects is shallower than predicted and 90 percent is deeper. That is, if one knows the history of ON potentials of a pipeline section, one can use the curve $r_{10\%}(x)$ to calculate the 10 percent quantile of the defect depth.

For each other quantile q, one can calculate a similar curve as well. The choice q=50% provides the curve with which the median defect depth can be calculated. Choosing q=97.5% provides the curve with which to calculate a defect depth that is exceeded only with probability 2.5 percent.

This is the interpretation of Figure 2. The graph shows the calculated curves r_q for the values of q that are displayed in the legend. These curves are empirical in that they have been calculated based on the actual data from the GTS network.

4 INTERPRETATION

All the curves in Figure 2 together provide an estimate of the statistical distribution of the corrosion rates at each potential. For example, it can be read from the graph that at an ON potential of -1400 mV, the 5 percent quantile of the probability distribution of the corrosion rates is 0.028 mm/year, the 10 percent quantile of this distribution is 0.03 mm/year, and so on.

The curves in the graph have a shape that is almost horizontal until close to -1000 mV. This means that the statistical distribution of the corrosion rate does not change much with changing ON potential, as long as this potential is more negative than -1000 mV.

This shape of the curves is the shape that can be expected if the defects in the data set have been caused by different corrosion mechanisms. The rate of some of these mechanisms depends on the ON potential, the rate of some others does not. In what follows, this will be demonstrated more precisely.

It can be expected that there are some defects that are caused by a corrosion mechanism for which cathodic protection is ineffective. The corrosion rate of these defects is independent of the pipe to soil potential, and hence also independent of the ON potential. This is the case, for example, for defects that are completely shielded or for defects inside isolating casings. Also, defects that are the result of AC or DC interference grow at a rate that is mostly determined by the intensity of the interference, and not by the pipe to soil potential.

In the hypothetical case that all defects would have a corrosion mechanism of this kind, the calculated curves would be expected to be horizontal over the entire domain. The resulting graph would look similar in shape to the graph in the following figure.

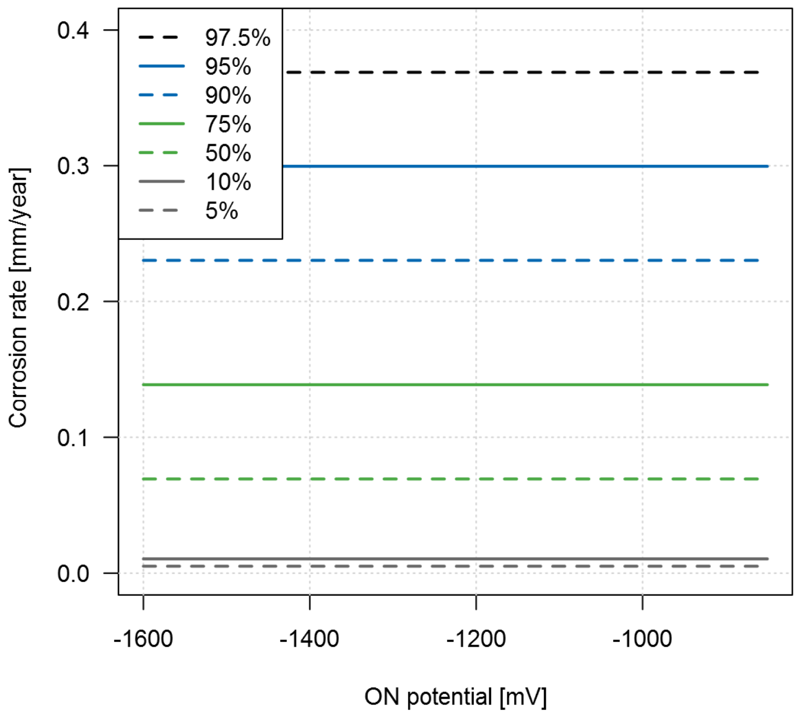

Figure 3: Illustration[2] of the expected shape of the curves if the growth rate of all defects were unaffected by the pipe to soil potential.

On the other hand, it can be expected that the growth rate of some other defects does depend on the pipe to soil potential. The growth rate of these defects increases with more positive pipe to soil potential. In the hypothetical case that all defects would have this behavior, the expected shape of the calculated curves would be similar to the graph in the following figure.

[2] The graph is meant as an illustration only and is not based on any data. The same holds for Figure 4 and Figure 5.

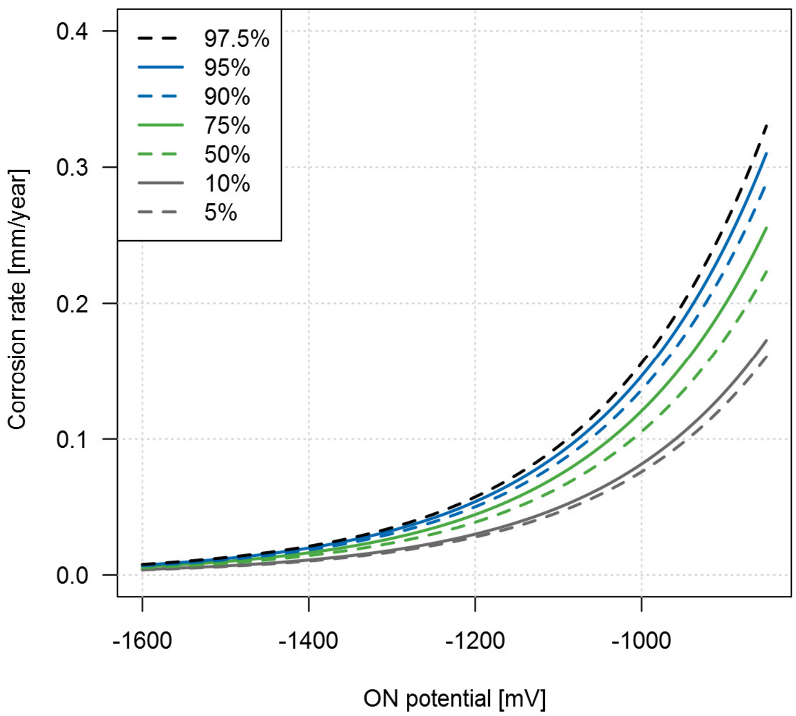

Figure 4: Illustration of the expected shape of the curves if the growth rate of all defects were determined by the pipe to soil potential.

The real data set is likely to contain both kinds of defects. The following graph has been computed for a fictional situation in which the corrosion rate of half of all defects behaves as in Figure 3 and the other half as in Figure 4.

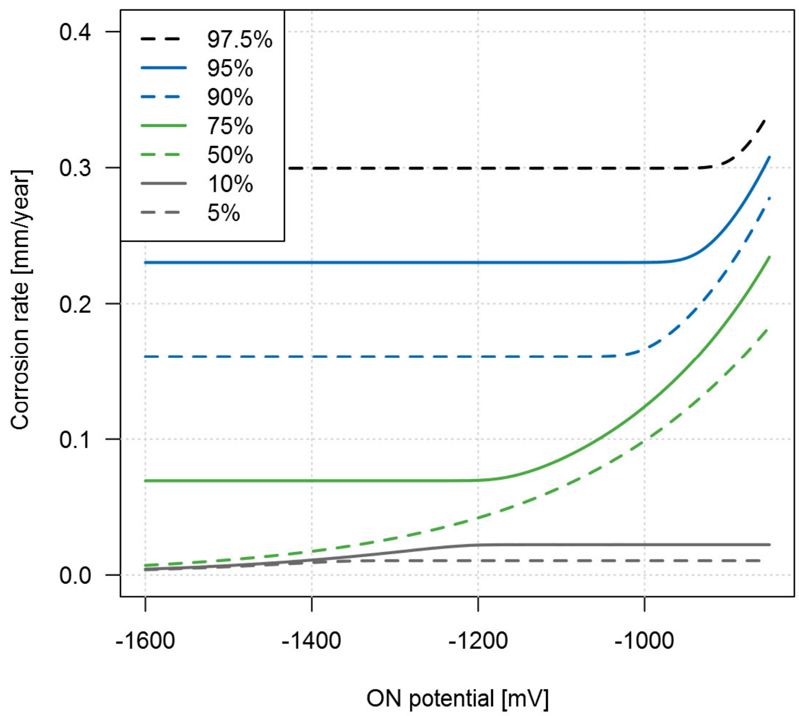

Figure 5: Illustration of the expected shape of the curves if the growth rate of half of all defects were unaffected by CP like in Figure 3 and the other half strongly affected by CP like in Figure 4.

Notice that the shape (not the actual numerical values) of the real curves in Figure 2 is remarkably similar to the fictional curves in Figure 5. In both graphs, the bottom curves first go up and then flatten off. The topmost curves start flat and peak at the right. This demonstrates that the shape of the calculated curves in Figure 2 is what one would expect if the total defect population consists of some defects whose growth rate is influenced by CP and some others whose growth rate is unaffected by CP.

5 DISCUSSION

5.1 Applicability

The potential-dependent corrosion rates that have been calculated correspond to the GTS network in the Netherlands. It is expected that the statistical distributions of the rates are specific for this network and do not apply to other networks. As exposed in the previous section, the curves take the shape that they do because of the occurrence of different corrosion mechanisms in the data set. Each network has its peculiarities in how susceptible it is to corrosion mechanisms such as shielding, AC and DC interference. It follows that one can expect different curves (i.e. different statistical distributions) for different networks. The approach to determine these curves does apply to other situations.

5.2 Validity

The potential-dependent corrosion rates that have been found are based on real data. However, it merits discussion that the data come with some limitations that affect the outcomes of the model. Research is ongoing to overcome this.

The pigrun inspections report only report external corrosion if the peak wall loss is over 10 percent wall thickness. Shallower defects go unreported. In consequence, deep defects are overrepresented in the data set.

Deep defects are those that have experienced a significant corrosion rate over a significant period in the first place. The corrosion rates are computed based on data from these deep defects. It follows that the estimated probabilities of high corrosion rates are overestimates.

On the plus side, for pipeline integrity management purposes the deep defects are the important ones. The current model enables to calculate the peak wall loss of these deep defects.

A possible way to overcome this, is to base the analysis either on excavation data or on data from corrosion growth analyses based on consecutive pigrun inspections.

In the model that has been presented, the corrosion rate is assumed to depend on the ON potential only. It has been attempted to incorporate other relevant information into the model (soil characteristics, groundwater level), but until now this has not produced results that can be applied in practice.

6 CONCLUSION

By matching the observed defect depths to the history of ON potentials, a relationship between the corrosion rate and the ON potential has been determined. The results enable to forecast corrosion growth based on the ON potential. Also, the results enable to assess the integrity of pipelines that are nonpiggable or that haven’t been inspected, provided that the historical ON potentials are available.

7 REFERENCES

[1] R. Coster: Statistical modelling of external corrosion based on CP history. Paper CEOCOR Congress, Ljubljana 2016.