Corrosion calculation for non-piggable pipelines

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Introduction

The corrosion activity in underground pipelines made of steel plays an important part in the evaluation of the technical condition of such pipelines. Ultrasound or magnetic flux leakage pigs are the preferred methods for the detection of existing corrosion attacks. A method which allows possible wall thickness decreases caused by external corrosion to be calculated has been developed for pipelines which do not allow the travel of such inspection tools. In this context, a range of spatially and chronologically discreet influencing factors are taken into account.

Principles of corrosion calculation

The technical integrity of underground pipelines made of steel is dependent on sufficient mechanical stability of the pipe wall amongst other factors. This can be impaired by local wall thickness weakening, which is caused by corrosion. In the case of natural gas pipelines, the relevant corrosion activity is restricted to the outer wall of the pipe. Internal corrosion does not play a very important role since the transported medium is normally dry.

Due to the consistent application of corrosion protection methods,

- coating,
- cathodic corrosion protection (CCP),
- leakage current protection,
- protection against alternating current corrosion,

corrosion damage to high-pressure gas pipelines is infrequent. The application of cathodic corrosion protection is, for example, legally required in Germany. Despite this, efforts are being made to provide objective information about the network condition. It is still necessary to plan for repair, rehabilitation or renewal costs on pipelines in both the medium and long term, especially in the light of network usage regulation. Persons in charge of operation and regulatory authorities require verification of technical integrity even on older pipelines.

In other words, the task definition is to detect, to identify and to locate any relevant wall thickness weakening which impairs the technical integrity of the pipeline.

An inspection procedure frequently used to solve this task is pigging using ultrasound or magnetic flux leakage sensors. The results of such intelligent pigging runs deliver good findings with regard in order to identify of local wall thickness weakening.

However, the construction of certain gas pipelines doesn't allow pigging. A lack of pig traps, radii at directional changes which are too small, steps in the nominal thickness, smaller nominal diameters or pressures which are too low often do not allow in-line inspection. The alternatives for condition assessment with regard to external corrosion are therefore correspondingly limited.

Condition assessments are therefore frequently made dependent only on the age of the pipeline or on malfunction statistics. Malfunction statistics are, however, less significant for high-pressure gas pipelines. The reason for this is the low frequency of malfunctions due to the basically well-functioning corrosion protection already mentioned. The dependency of the corrosion behaviour on the age of the pipeline is established. As we know, corrosion of iron is an integral procedure over time. It does, however, lead to large errors if other influencing factors are not taken into account.

The question of the timeframes during which the active and passive corrosion protection measures mentioned above were present at a specific quality level is of particular importance. Passive corrosion protection in the form of coating can initially be assumed to apply over the entire service life of a high-pressure gas pipeline. However, the qualities provided by coating systems are extremely varied. In this context, dependency of the coating quality on the age of the pipeline does not have a linear correlation. On the contrary, there have been abrupt changes in the technological development of coating systems which have even occasionally included retrograde steps. The transition between bituminous and plastic materials, which mainly took place during the 1970s, can be stated in this case as an example. Some of this earlier PE coating results in much greater problems than the tried and tested bitumen coating previously used (cf. Figure 1 / Figure 2).

Figure 1: Pipeline constructed in the 1980s, coating made of PE [own photo]

Figure 2: Pipeline constructed in 1954, coating made of bitumen [own photo]

In the end, all the various coating systems are subject to differing ageing mechanisms. It would make sense at this point to differentiate the assessment of technical pipeline conditions with regard to possible corrosion procedures.

The application of CCP using external electricity behaves in a similar manner. In contrast to coating, it is not possible to assume overall application since construction of the pipeline. Countrywide application of the electrochemical protection process took place in Germany from around 1960 onwards, and it was only incorporated in the technical rules and regulations for high-pressure gas pipelines (DIN 2470, DVGW Code of Practice G 463) for the first time in 1967. The quality of protection was increased over the course of time, especially due to improvements in the measurement procedure for verifying the effectiveness of CCP. Countrywide application was achieved through integration of the improved procedures in the technical rules and regulations. We must also assume discreet quality levels at various times in this case.

Further relevant influences on corrosion behaviour are:

- the soil composition,
- influences caused by leakage currents,
- influences caused by high-voltage,
- special structures (casing pipes, culverts, HDD routes, …).

The question of how the stated influences can be sensibly assessed in order to achieve measurable and comparable results must therefore now be asked.

The corrosion speed in µm/a was selected as a suitable parameter.

In one study [1], relationships between the corresponding influence factors and the corrosion speeds V_{corr} to be assumed from these were defined. In this context, values from technical rules and regulations, information taken from literature, and empirical values from long-standing application practice were considered.

Corrosion calculation operating mode

The pipeline condition caused by corrosion can be represented by calculating the predicted total corrosion ablation $s_{corr\text{-}total}$ which allows the identification of local corrosion failure of a pipeline. We intend to consider the process and functionality of this calculation in more detail in the following text. The developed classification scheme is based purely on electrochemical corrosion processes[1] for underground and typically non-alloy or low-alloy steel pipelines for which the pre-requirements for the application of cathodic corrosion protection in accordance with [4] exist.

Probability assessments of the occurrence or prognoses of possible corrosion speeds of pitting corrosion were carried out as a matter of priority. This takes place primarily based on soil aggressiveness (soils classification in accordance with [5] or [6]) and an assessment of the effectiveness of the corrosion protection.

The necessary incoming data, which firstly originates from the equipment documentation (GIS system) and secondly from the CCP documentation (CCP management system), is defined in this context. These include, amongst others, the laying procedure, the CCP protection system-based object length, the soil class (soil resistance), the soil inhomogeneity, the longitudinal electrical conductivity, statements with regard to the CCP effectiveness etc.

The following incoming data are also used to define segments:

- pipeline construction year
- original coating
- post-coating
- time of post-coating
- CCP start of operation
- soil class
- laying method (e. g. trenchless laying, insertion of product pipe into casing, etc.)
- CCP protection system[2]

Sections of similar incoming data are defined by segmentation, which enables a distinct prognosis of a possible overall corrosion ablation applicable to this section (cf. Figure 3).

[1] In order to determine a maximum corrosion rate which depends on the corrosion influences, influences caused by free corrosion due to the surrounding electrolytes and caused by formation of ventilation elements and soil homogeneity, in addition to corrosion due to local voltage gradients in the soil, stray current corrosion due to changing DC effects over time and alternating current were taken into account. In this context, corrosion caused by element formation with external cathodes, stress corrosion cracking, corrosion due to influences caused by high-voltage direct current transmission, corrosion under removed coating and corrosion due to telluric effects was not taken into account [1].

[2] A CCP protection system is the term given to a conductive piping section (electrically continuous in the sense of cathodic corrosion protection) in which a cathodic protection system has been installed.

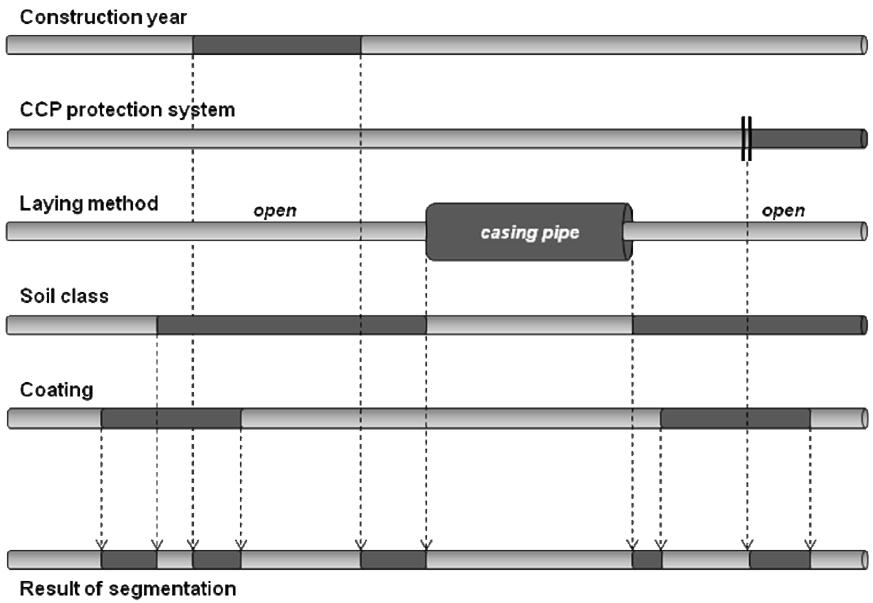

Figure 3: Sample segmentation using reduced incoming data [own diagram]

The procedure continues as follows:

- Program-controlled determination of the corrosion rate for a segment within a defined validity period of the corrosion parameters used as a basis
- Program-controlled determination of the corrosion ablation for the segment for the applicable validity period of corrosion parameters
- Program-controlled summation of corrosion ablation for a particular segment over all validity periods
- Possibility of transfer of corrosion ablation for all segments based on the observed pipeline section as an incoming quantity for a Pipeline Integrity Management System (PIMS)

The determination of the possible corrosion ablation principally takes place through observation of the major life cycles (from the corrosion-protection point of view) of an underground steel pipeline, the period before setting up the CCP and the period after setting it up. This aspect has been taken into account through the development of two different assessment algorithms. Non-existence of the concentration element formation is assumed for the assessment of the cycles with CCP, so that only the free corrosion rate is

taken into account for the determination of the resulting corrosion rate for the respective cycle. Furthermore, a maximum corrosion rate[3] of 10 µm/a is assumed for the period of the effectiveness validation when verifying the effectiveness of the cathodic corrosion protection system in accordance with [7].

The individual corrosion rates (cf., for example, Figure 4 $v_{corr\text{-}inhomogenous}$) are based on a base corrosion rate derived from the soil classification as far as possible. This achieves a uniform comparison on a simple basis for the evaluation of the various corrosion processes. The strength of manifestation of the respective corrosion rate is adapted using appropriate correction factors.

The precise process for the prognosis of the possible corrosion rate is made clear in the following text on the basis of the concentration element formation for non-CCP-protected pipelines (Figure 4).

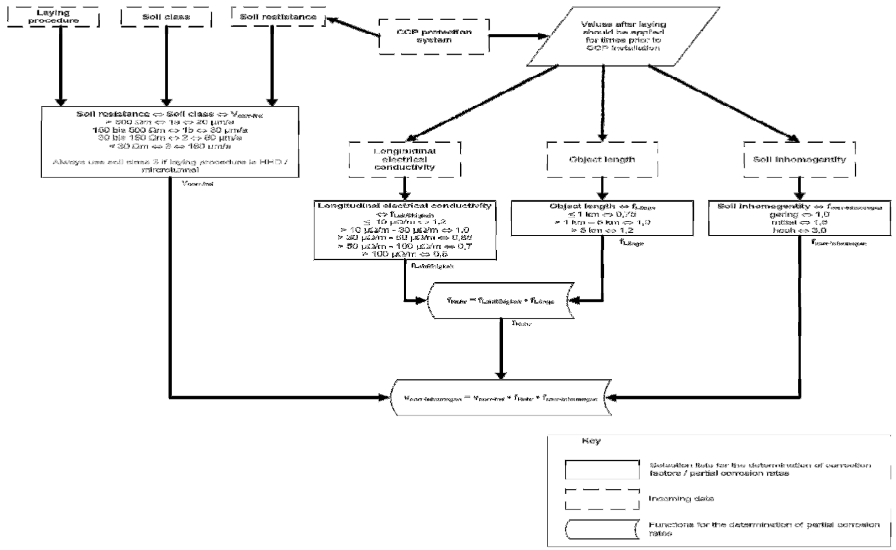

Figure 4: Section of logic corrosion calculation [own diagram].

In the prognosis of a possible corrosion rate due to the formation of extended concentration elements over the period before setting up the CCP, the influence of the longitudinal electrical conductivity coating, the absolute object lengths and the soil inhomogeneity on the corrosion speed were taken into account through the $f_{corr\text{-}inhomogenous}$,

[3] Possible corrosion rates of 30 µm/a in accordance with [9] were not explicitly observed since the rules and regulations applicable at the time of developing this methodology were [8].

$f_{conductivity}$ and f_{length} correction factors. The derivation and verification of these factors will be omitted at this point and attention drawn to the methodology [1].

The following incoming data is assumed for explanation of the process of determination of the corrosion rate $v_{corr-inhomogenous}$ for a specific segment in accordance with Figure 4:

- Construction year: 1955
- CCP start of operation: 1960
- coating type: bitumen
- Length of pipeline: 15 km
- Nominal diameter: DN 200, external diameter: 211 mm
- Wall thickness: 5.5 mm
- Maximum operating pressure (MOP): 16 bar
- Laying procedure: open trench
- Soil resistance: 100 Ωm
- Soil inhomogenity: medium
- Longitudinal electrical conductivity[4]: 50.29 µΩ/m

The fact that the pipeline was laid using the "open trench" procedure means that the derivation of the basic corrosion rate was determined from the actually applicable soil resistance or soil class. A basic corrosion rate of 80 µm/a was therefore assumed accordingly for further calculation (soil class 2: 30 – 150 Ωm). In addition, the f_{pipe} and $f_{corr-inhomogenous}$ factors were derived from the remaining incoming data. The resulting corrosion rate of $v_{corr-inhomogenous}$ then results from the product of both factors and the basic corrosion rate. A value of 1.5 for $f_{corr-inhomogenous}$ results from the mean soil inhomogeneity. The factor f_{pipe} is composed of the $f_{conductivity}$ and f_{length} factors. Analog to the $f_{corr-inhomogenous}$ factor, the incoming data provides values of f_{Length} = 1.2 and $f_{conductivity}$ = 0.7. The factor f_{pipe} = 0.84 results from this. If the parameters determined in accordance with the logic used in Figure 4 are inserted into the appropriate formula, the corrosion rate resulting is:

$v_{corr-inhomogenous} = v_{corr-free} \times f_{pipe} \times f_{corr-inhomogenous}$[5] = 100.8 µm/a

Possible corrosion rates for influencing through static voltage gradients, through stray currents with chronological changes and through alternating current were calculated in addition to this corrosion rate for the purpose of determining the overall corrosion rate

[4] Determined using the formula for specific longitudinal electrical conductivity from the external diameter and wall thickness of the pipeline [1].

[5] Calculated values in accordance with this equation correlate to the approximations for corrosion rates which are stated in [5] dependent on the soil class. The corrosion rates stated in [3], which were determined on sample metal sheets, were maintained if short pipe lengths for f_{length} were used as a basis [1].

using the same method[6]. After the formation of the overall corrosion rate for this special segment, this was then multiplied with the period of validity for the corrosion parameters, which leads to a predicted partial corrosion ablation[7].

This process takes place as described above for every segment for the appropriate validity period of corrosion parameters and subsequently leads to the predicted overall corrosion ablation $s_{corr-total}$, which is calculated as follows:

$$s_{corr-gesamt} = \sum_{n=1}^{i} (s_{corr\_n-i}) \quad \text{with i = number of single cycles}$$

The complete assessment logic was comprehensively and auditably modelled in a logic circuit.

Integration of the corrosion calculation in a PIMS

The calculated material ablation is normally based on information which is of variable reliability. Firstly, assumptions about non-documented incoming data must sometimes be made in order to carry out a calculation at all. It depends on the user how conservative or progressive these assumptions are made. It is, of course, clear that the calculation results can be influenced in this way[8].

A useful approach can be to set assumption values for all non-secured incoming data in such a way those probable values are used respectively which cause the highest corrosion rates. This procedure is considered conservative. It results in correspondingly large calculated material ablations.

If this conservatively calculated wall thickness weakening is acceptable in further integrity observations, no further stages are necessary. If the conditions derived from the corrosion calculation are critical, specific inspections which result in more precise information on the assumed incoming values should be carried out. Results with a greater accuracy can now be achieved during further corrosion calculations.

One of the most important factors for the corrosion process is, as previously noted, the quality of the coating. No corrosion will actually take place in areas where the coating has no defects. The phenomenon of corrosion underneath detached coating is not covered by the corrosion calculation.

Since it is not normally known where the coating on the pipeline under observation is intact or damaged, a conservative approach which assumes that the coating has been damaged

[6] In the case of verification for a defect-free coating at PE layer thickness of 3 mm, a corrosion rate of 2 µm/a was applied across the board for the observed period (cf. [3], note: Defect-free coating can be assumed with a coating resistance ≥ 10^8 Ωm²) in practice.

[7] The validity period for the determination of the corrosion ablation for this example is the period without CCP, and is therefore the year of CCP start of operation minus the year of pipeline construction (5 years).

[8] Uniform criteria for the interpretation of available CCP data and the setting of assumption values have been secured in the form of a manual for corrosion calculation.

at a specific location shortly after or during laying will only provide a statement about how large a specific wall thickness weakening can be, but not about where it could be located.

The PIMS in which the corrosion calculation is embedded therefore makes it possible to take results from intensive measurements or variations on this into account; these measurements are suitable for detecting locations of coating defects. This means that the locality of calculated wall thickness weakening can be localized. If intensive measurement results which are dated considerably before the performance of the corrosion calculation are available, they can also be taken into account. The calculation of possible material ablation for areas which have been identified during such measurements as free of coating defects therefore first starts at the corresponding time of the measurement.

The same also applies to results from intelligent pigging runs. In this case, the corrosion calculation starts from the time of and with the values from the last wall thickness determination. In principle, the corrosion calculation was designed for non-piggable pipelines, but it can also be meaningfully applied to piggable pipelines in the course of condition assessment.

Conclusion

The corrosion calculation presented is a very good instrument for approaching technical condition assessment of underground steel pipelines which cannot have pigging runs carried out with regard to possible wall thickness weakening due to external corrosion. The strength of this approach lies in the differentiation during evaluation of the technical pipeline condition with regard to possible corrosion processes, which means that it provides a good alternative for condition assessment based on, for example, the pipeline year of construction and the malfunction statistics. Furthermore, the possibility to carry out a corrosion calculation based on existing documentation and to supplement missing values with assumed values is of central importance in the assessment of historical processes. The combination of literature- and practice-based values, i. e. the maximum theoretical corrosion rate and empirical values, provides a realistic basis for the evaluation. In order to reduce insecurities due to the assumptions and simplifications applied to the calculation model and to the incoming data, the corrosion ablation calculated with the help of the corrosion calculation can be systematically checked with the help of pigging and excavation results in addition to extended data research.

The results of the corrosion calculation are not comparable with intelligent pigging runs in terms of meaningfulness. However, the corrosion calculation provides an effective assessment system for non-piggable pipelines.

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Translator's note: The references listed in the original document have been left in the original language of German.

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