ATMOSPHERIC CORROSION
Preventive Measures
in Maintenance Phase

NTT Consultancy
Giel Notten
Senior Corrosion Engineer

Contents:

1. Introduction

From the cases of atmospheric corrosion and the conditions that are conducive to such corrosion we have formulated a number of preventive measures. They are taken at three different points in time, during the:

- Engineering phase;

- Construction phase;

- Maintenance phase.

The preventive measures during the Engineering phase and the Construction phase have been covered in UreaKnowHow.com Mechanical Paper of September 2009. This paper covers the preventive measures during the Maintenance phase.

2. Preventive / predictive measures in maintenance phase

During maintenance, too, insulation and protective coatings are often overlooked. First and foremost, it is essential that the management should be aware of the risk of atmospheric corrosion. That awareness should be transferred to the workforce via a communication program, training courses and a detailed corrosion control plan.

Periodic inspections should be made to assure the long-term reliability of equipment and piping. When the cover sheeting is found to be damaged in any way, it should be repaired without delay.

Inspections for atmospheric corrosion should distinguish between plants in which preventive measures have already been taken (e.g. a coating to DSM Standard EP 7-3.1) and plants where such measures are yet to be taken. Such periodic inspections are especially important where atmospheric corrosion may lead to hazardous situations or production outage.

Hazardous situations may arise in each of the following cases:

- a high energy content, i.e. $P \times V \geq 50$ bar m^3
- operating pressure $P_w > 40$ bar
- hazardous process fluids such as those with Inspection Class A, B or C to DSM Standard EP 3.2.2-1.1 or caustic or acidic fluids classed R2 to the same standard.

No hard and fast rules can be given with respect to the economic consequences. These can only be assessed on a case-to-case basis.

Plants that have been treated in conformity with DSM Standard EP 7-3.1 should be periodically inspected. The first spot checks should be made about five years after commissioning. The nature and extent of inspection should be established in consultation with an expert, and any defects found should be repaired. The frequency of subsequent inspections depends on the results of the first inspection.

Plants that are not protected to DSM Standard EP 7-3.1 (mostly those older than about fifteen years) but require a DSM protective system should be inspected as soon as possible if warranted by safety and economic considerations.

If leakages are unacceptable from a safety point of view, ensure that the plant complies with DSM Standard EP 7-3.1.

An inspection schedule, based on selection criteria and inspection techniques, should be drawn up in consultation with an expert.

Lay-out and construction criteria may be applied for the purpose of selecting potential critical areas where insulated equipment and piping need to be inspected for atmospheric corrosion. Such areas will need to be designated in the plant on the basis of the drawings, particular attention being given to the following aspects:

- Damage to and/or leaks (e.g. faulty overlap) in insulation jacketing
- Bends at the low end of vertical pipelines
- Supports and passages through the insulation jacketing
- Initial and end of the insulation particularly for vertical pipelines
- Drains (dead line sections such as sampling points) and vent pipelines
- Location relative to, for instance, cooling towers (in the prevailing wind direction)
- Areas where apparatus is cleaned by water-jetting
- Apparatus and pipe work with sprinkler systems
- Apparatus and pipe work affected during fire-fighting drills
- Lowest point of sloped pipe line
- insulation covers of valves and fittings
- Additional shell cooling of heat exchangers
- Damaged fire proofing (including water deflectors)
- Field welds in lines requiring inspection by authorized inspector
- All areas where any abnormality is observed, such as rust, moss growth, ice
- Leaking trace lines and steam tracing installed without spacers
- Application of de-icing salt (urea instead NaCl!)

A spot check based on these aspects need not necessarily reveal every corrosion area. Experience has shown that moisture penetrating through leaks in the insulating jacketing is liable to spread over larger distances. It has been found that random visual inspections based on specific inspection criteria are no guarantee that all corroded spots are detected. From about 13,000 measurements we concluded that about 80% of the spots that urgently needed repair were in critical areas that could have been identified beforehand on the basis of well-defined criteria. These spots covered about 20% of the total pipe length (Figure 9). If for reasons of safety or reliability you want to have full assurance, you will have to strip down all insulation for a complete inspection.

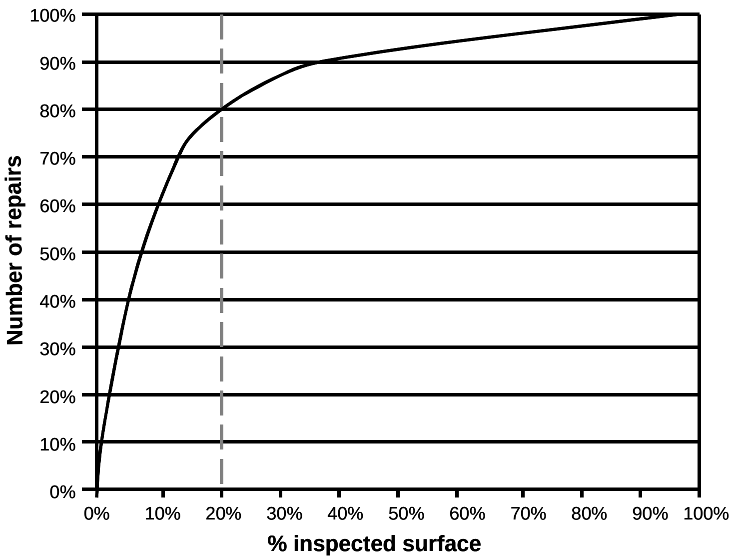

Figure 9: Repairs vs. inspections based on 13,000 measurements

3 Protection of bolting and screwed joints

Up until the 1970s, bolting used in the CPI was mostly cadmium-plated, and in general this gave fairly good performance, although there were isolated cases of LME (liquid metal embrittlement) or SMIE (Solid Metal Induced Embrittlement). As cadmium-plated were gradually phased out for environmental reasons, DSM changed over to Never Seez for bolt protection. As an alternative graphite-based compounds were used for temperatures up to 80 °C whilst Molykote HSC was found to be acceptable for low-alloy and unalloyed carbon steel.

Of late, however, Never Seez has fallen into disfavor because its active ingredient, powdered nickel, is a pollutant. Also, even if Never Seez is applied, slackening bolts can still be problematic because of corrosion or galling.

Corrosion of unalloyed and low-alloy bolting in outdoor plant can be lessened by applying a suitable coating. We know from research and experience that coatings such as Xylan 1070 (a mixture of fluor polymers in an epoxy matrix,) applied on zinc coated bolting, give good performance at temperatures up to 250 °C. Anti-seize compounds are less effective when it comes to corrosion prevention. For indoor plant, where corrosion is highly unlikely, a coating or Molykote P37 may be used. Molykote P37 is a ceramic paste made up of zirconium oxide, graphite and calcium oxide in sulphur-free synthetic oils.

Bolts and nuts in austenitic stainless steel and aluminium are prone to galling, especially if the mating surfaces have equal hardness. It has been found that galling can be prevented by applying a coating such as Xylan 1070, to one of the surfaces. A coating gives better performance than an anti-seize compound at temperatures up to 250 °C.

At temperatures higher than 250 °C, where electrochemical corrosion is much less of a threat, we always use an anti-seize compound such as Molykote P37.

For the selection chart of an appropriate bolting protection system, see selection chart Figure 10.

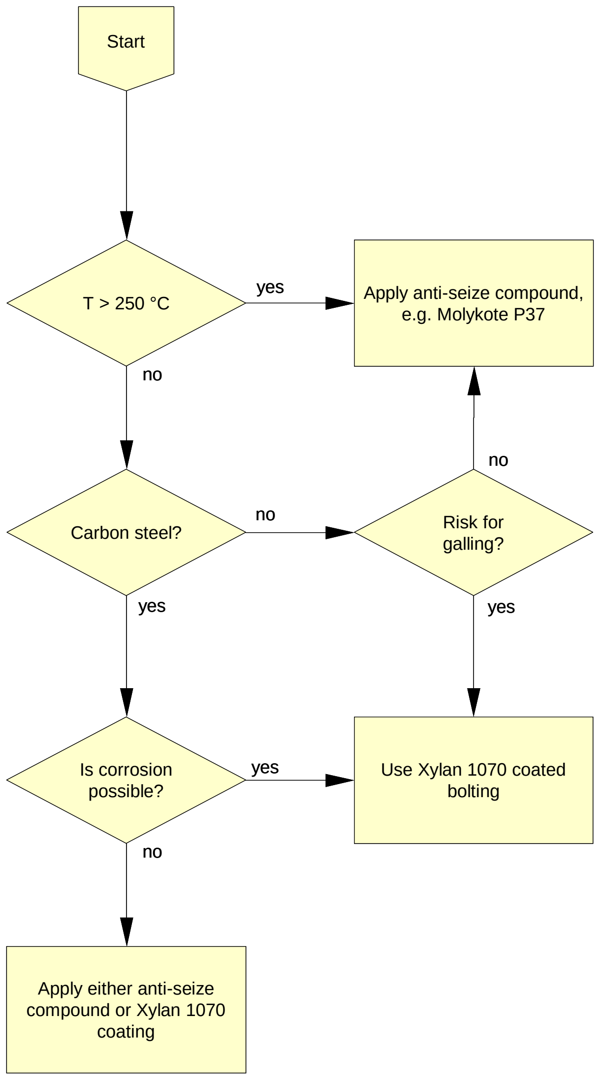

Figure 10: Selection chart for bolting protection

4 Inspection techniques

A number of inspection techniques may be used for detecting corrosion, depending on the form of corrosion and the material of construction. These techniques are:

- Overall corrosion (crater-like attack):
  - visual inspection after removing the insulation
  - radiography (isotope)
  - flash radiography
  - ultrasonic testing
  - total magnetic flux method
  - eddy current testing
  - TEMP: Transient Electro Magnetic Probe
- Crack-initiating corrosion (stress corrosion cracking and hydrogen embrittlement)
  - Dye penetrant testing
  - Magnetic particle testing
  - Eddy current testing

As far as reliability is concerned, it is best to strip the insulation and then inspect the metal surface, visually or otherwise. But this is arduous and costly. Thus, there is a need for a reliable, non-destructive method specially developed for insulated piping and equipment.

The former Corrosion and Materials Department of DSM has tested a number of methods for their suitability, most notably flash radiography, the TEMP method (Transient Electro Magnetic Probe) and the Guided Wave Pipe Inspection Technique.

4.1 Flash radiography

For flash radiography we use a portable, battery-powered X-ray machine, also known as the ‘Inspector’. It has a low-energy radiation source and emits pulsed X-rays (Photo 1). Penetration in steel is limited and usually no indication is obtained of the metal thickness.

Corrosion is made visible as a rust scale in the insulation material (Photo 2) as variations in the pipe contours. We have found flash radiography to be useful for a first exploratory investigation (spot checks) to detect atmospheric overall corrosion and crater-like attack.

Photo 1: Inspection of insulated pipeline based on radiography technique

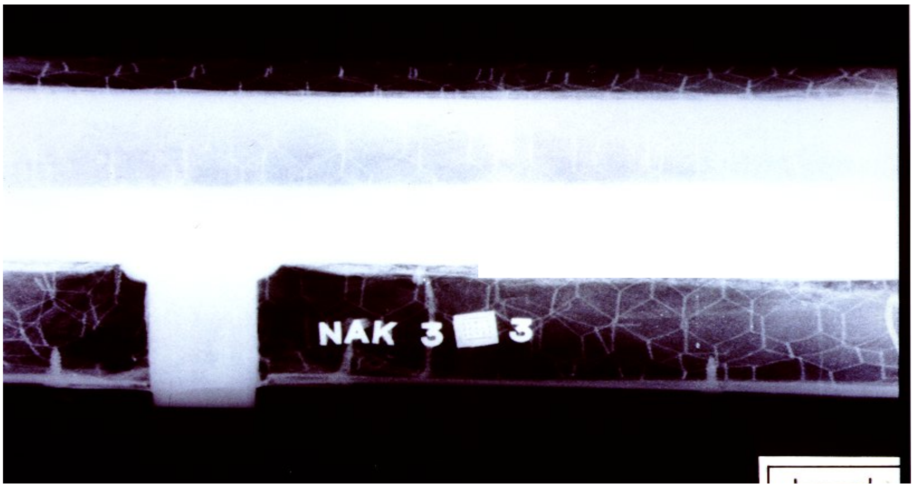

Photo 2: Picture of insulated pipeline taken with the aid of flash radiography

4.2 TEMP

The TEMP method was developed by ARCO Exploration and Production Technology, of Texas, U.S.A., and is based on pulsed eddy-current testing method.

The pipe wall thickness can be measured with an accuracy of 0.5 mm as the average for an area of Ø 50–100 mm (spot checks). In our experience, this method is not yet reliable enough for the present purpose. Accurate measurement of the remaining wall thickness is hampered due to the fact that the technique actually measures the volume of material underneath the probe (area about Ø 50–100 mm), rather than a wall thickness. Therefore small crater-like defects or pitting are not detected. Also, erroneous readings are produced by nearby metal objects such as nozzles and reinforcing rings, especially if they are nearer than 300 mm.

In our view, the TEMP method is not yet reliable enough to detect corrosion beneath the insulation in critical areas such as nozzles and pipe supports. We expect, however, that sooner or later an improved design, giving better resolution, will come on the market.

4.3 Guided Wave Piping Inspection Technique

The Guided Wave Piping Inspection Technique is a novel so called “long range ultrasonic inspection” method.

The guided waves technique has the potential to detect corrosion or damage to otherwise inaccessible pipe sections. Examples are corrosion under insulation and supports, road crossings and other hidden penetrations.

Theoretical overview

“Guided waves” is a general name for the kind of wave propagation, in arbitrary geometry, which most NDT personnel know by its appearance as Lamb waves in plates. Since a wave group is transmitted along the whole circumference of the pipe, there is no geometric spreading. Therefore the attenuation is low, and the possible detection range is long. Applying low frequency and consequentially long wavelength makes the attenuation lower and the detection range longer. The frequency is in the range of 20 to 100 kHz. Bare pipes can be inspected over distances up to 50 m. Attenuating surface conditions such as bitumen coating or the pipe being buried decrease the range.

Guided waves are described in terms of wave modes. Commonly longitudinal, flexural and torsional modes are used. The waves are generated in the pipe with two or four probe rings, containing piezo-electrical elements. These rings are either rigid or inflatable. The system can in principal be used on pipe diameters of 1 to 36”.

Theoretically the inspection range can vary from 50 m (clean pipe, no coating or heavy corrosion) to 5 m (heavy bitumen coating).

The surface at the location where the probe ring is applied needs to be free of loose scale and loose paint. The system works fine with good paint layer. Insulation has to be removed to mount the ring (small area), but can remain in place over the rest of the inspection range.

The system can look past supports or bends in the pipeline.

Welded supports can interfere with the effectiveness of the inspection. Also the system can look through girth welds. Welds can be clearly picked up with the system and are a great help in locating defects as they enable better calibration of the system. However the system cannot look through flanges.

Operational benefits and experiences of former Corrosion and Materials Department of DSM

With this novel technique corrosion under insulation can be detected easily over a large distance (up to 50 m in two directions, so from one inspection point up to 100 m), without removing the insulation (only locally). Wall loss due to atmospheric corrosion as low as 5 % of the nominal wall thickness can be detected. The system however can give only a rough estimation of the residual wall thickness (qualitative evaluation of the signals). The system is highly portable and battery packed, so it is easy to operate in the field. Each measuring point takes about 5 min (inclusive mounting and dismounting of the test ring).

This novel technique has high potentials as an appropriate cost effective screening technique for the detection of atmospheric corrosion of insulated piping. However, further improvements with respect to accuracy have to be developed.

5 Rejection criteria for corroded pipelines

Atmospheric overall corrosion and crater-like attack is attended by loss of wall thickness. The decision to replace or repair the affected pipeline should be based on objective rejection criteria derived from stress analysis.

A distinction should be made between the tangential stress exerted by the internal pressure and the axial stress resulting from the internal pressure and weight.

The wall thickness required by the tangential stress (d_{tan}) and the axial stress (d_{ax}) can be determined by calculation. Using the LOTUS 1-2-3 computer program, an inventory can be made of pipelines with varying diameter, wall thickness and insulation thickness. For each pipe diameter a matrix is produced showing the minimum required wall thicknesses d_{ax} and d_{tan} as a function of the internal pressure and, if we are dealing with a straight pipe run, the support spacing. The greater wall thickness is the minimum required wall thickness (Table 4). This method often produces values for the minimum required wall thickness that are unrealistic, for instance less than 1 mm.

In practice, additional to the matrix values, it is best to stick to the following lower limits:

DN < 50 mm: d = 1.5 mm

50 < DN < 200 mm: d = 2.0 mm

DN > 200 mm: d = 0.01. DN

The following questions should also be considered:

- Is the pipe subjected to any concentrated loads, e.g. valves?
- Does the pipe vibrate anywhere?

Figure 10 presents examples of required minimum wall thickness by weight and internal pressure.

Table 4: Minimum residual pipe wall thickness as rejection criterion for piping subject to atmospheric corrosion.

YSθ_m (θ_m = 200°C) [N/mm^2] : 182 density environment [kg/m^3] : 700 density metal [kg/m^3] : 7849 density of insulation [kg/m^3] : 117	PN	d(ax) WE+PR			d (tan) PR
Support distance [m]		2.0	3.0	4.0	
outside diameter [mm] : 33.7 wall thickness [mm] : 2.6 insulation thickness [mm] : 40	6	0.2	0.4	0.7	0.1
	10	0.2	0.4	0.7	0.1
	16	0.3	0.5	0.7	0.2
	25	0.3	0.5	0.8	0.3
	40	0.4	0.6	0.9	0.5
	64	0.6	0.8	1.1	0.9
Support distance [mm]		4.0	5.0	7.0	
outside diameter [mm] : 88.9 wall thickness [mm] : 3.2 insulation thickness [mm] : 50	6	0.4	0.6	1.1	0.2
	10	0.5	0.7	1.2	0.4
	16	0.6	0.8	1.3	0.6
	25	0.8	1.0	1.5	0.9
*ASTM A 106 grade B	40	1.1	1.3	1.8	1.4
	64	1.5	1.7	2.2	2.3

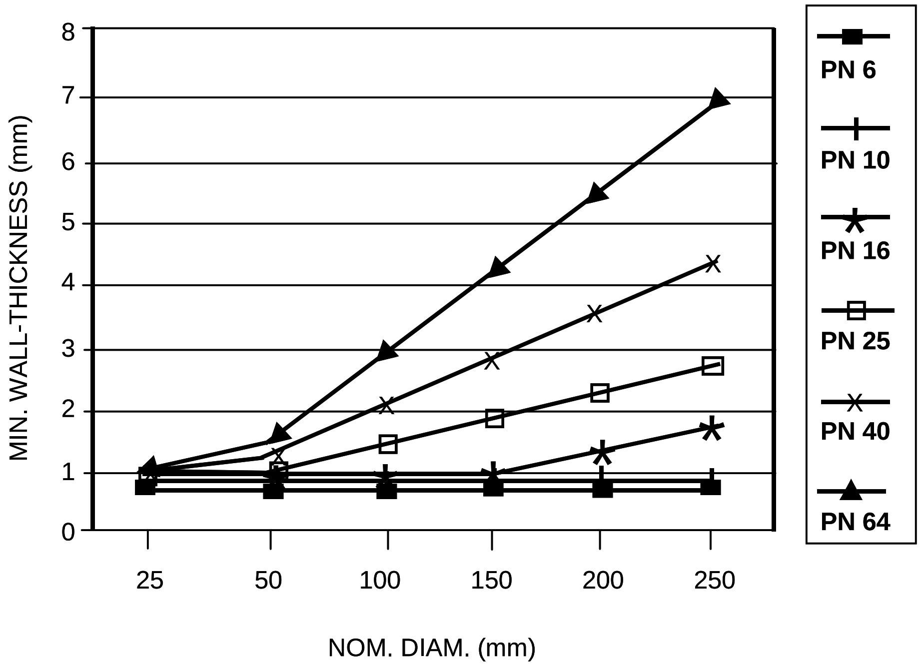

Figure 10: Required minimum wall thickness by weight and internal pressure.

6 Corrosion monitoring

The former Corrosion and Materials Department of DSM has studied the suitability of a number of corrosion monitoring techniques including the following:

- measurement of the electrical resistance of a corrosion coupon (corrosometer probe) or of a wire (Wrede and Niedecker)
- measurement of the electrical capacitance of the insulation and the organic coating on the metal.

A problem with these techniques is that the location of the monitoring probe need not necessarily be a corrosion site. Electrical capacitance measurement is capable of monitoring a larger surface area than the electrical resistance probe.

A drawback of capacitance measurement is that it does not measure corrosion but, rather, moisture absorption.

The provisional conclusion is that these monitoring techniques are not yet capable of detecting atmospheric corrosion at an early stage with sufficient reliability. More research is needed on suitable monitoring techniques.

7 Conclusions

- Atmospheric corrosion is a serious threat to the safe operation of, especially older, (petro) chemical process plant.
- If a hazardous situation might arise or if there is a risk of production outage, preventive / predictive maintenance with respect to external corrosion, should be carried out rather than breakdown maintenance.
- Conditions promoting atmospheric corrosion as well as requirements regarding preventive measures should be laid down in adequate standards.
- Application of painting systems and insulation systems if necessary, should be performed according to the requirements in these standards regarding product quality as well as guidance and control.
- Adequate protective coatings can extend the safe running period of (petro) chemical plant by as much as ten years. Extension by at least another ten years is possible by implementing a consistent inspection and maintenance programmed.
- Experiences show that application of a thermal spray aluminium coating generally requires minor maintenance. Despite higher investments costs it is expected that in many cases the life cycle costs are lower. For that reason application of thermal spray aluminium coating is promoted more and more to combat atmospheric corrosion of carbon steel piping and equipment.
- It is essential that management is aware of the risk and consequences of atmospheric corrosion. That awareness should be transferred to the workforce via communication programmed, training and a detailed corrosion control plan.
- The Guided Wave Piping Inspection Tool (“long range ultrasonic inspection”) is a promising non destructive testing method for inspection of (insulated) piping with just local removal of insulation. However, improvements in accuracy have to be developed.
- More research is needed for developing reliable inspection and monitoring techniques for insulated piping and equipment.
- A corrosion control (inspection and maintenance) plan has to be developed, based on RBI (risk based inspection) philosophy. This plan should comply with the work process of IER (Improve Equipment Reliability) according the manufacturing excellence philosophy.

8 Literature

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William G. Ashbaugh, ‘Inspection of Vessels and Piping for Corrosion Under Insulation’, *Materials Performance*, July 1990, p 38-42.

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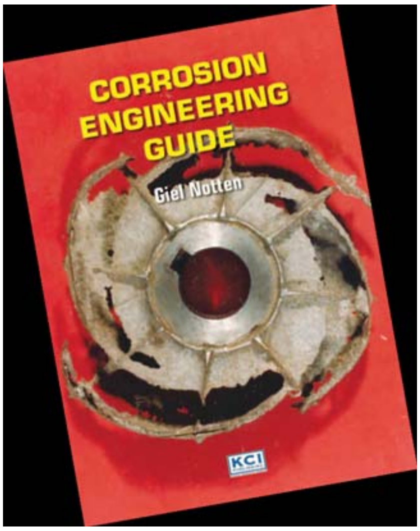
This paper is part of Giel's Corrosion Engineering Guide, a valuable asset for any engineer working in a urea plant.

This guide is available via:
http://www.stainless-steel-world. com/
Please find the Table of Content of this Corrosion Engineering Guide herebelow.



About Giel Notten

Giel is a true materials and corrosion expert who, before his retirement in 2004, spent thirtyeight years working with DSM in The Netherlands. After gaining his Engineering degree at the Higher Technical School of Heerlen, The Netherlands, he joined DSM's central laboratory.
He was to remain with the company for the rest of his career and held several positions as a materials and corrosion expert there. For the last twenty years before he retired, Giel worked in the Corrosion Department as Managing Senior Corrosion Engineer. He has further participated in numerous conferences spreading the word about his broad experiences as a corrosion and materials specialist in chemical process plants.
For Stamicarbon, a subsidiary company of DSM, and licensing DSM's know-how, he set up programmes for lifetime extension studies in urea and ammonia plants and supervised them.
He was also involved in the development of Safurex®, the super-duplex stainless steel grade (developed by Sandvik in cooperation with Stamicarbon) for application in Stamicarbon urea plants.
Giel has always enjoyed teaching so, after only five years working in the field at DSM, he already began to develop a Corrosion Engineering course. Since then he has taught many young engineers from both inside and outside DSM about the ins and outs of corrosion control in chemical plants. He was also a board member of NACE Benelux and a member of the Contact Group Corrosion of the Dutch Chemical Process Industry and the Studiekern Corrosion of the Dutch Corrosion Society (NCC).
Since his retirement from DSM, Giel Notten has remained active as a corrosion engineering consultant. He has devoted much of his time to passing on his extensive knowledge and experience on the complicated topic of corrosion engineering to a new generation of engineers.
He has done this in the form of numerous corrosion courses and workshops.
Alongside his professional career, Giel has been very active in local societies and has been a Rabobank board member for about thirty-five years, twenty-five years of which as Chairman of the Board. Furthermore, he is an active cyclist. Together with his wife, Lianne, he has made trips up to 2500 km by bicycle to Santiago de Compostela, Spain and Rome, Italy.

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