

EFFECT OF CATHODIC PROTECTION LEVELS AND DEFECT GEOMETRY ON THE A.C. CORROSION ON PIPELINES

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Abstract

In recent investigations it was found that the level of cathodic protection has an influence on the a.c. corrosion rate observed on coupons. In order to obtain data for optimizing the cathodic protection parameters, the corrosion rate was investigated at various On potentials and interfering a.c. voltages. Based on the obtained results it was possible to demonstrate that the corrosion rate can significantly be decreased if the Off potential is more negative than -0.85 V CSE and the On potential is in the range of -1.2 V CSE. Moreover it was possible to demonstrate that the high a.c. corrosion rate on coupons can readily be decreased if the cathodic protection level is adjusted. Hence, the lifetime of cathodically protected pipelines showing high a.c. corrosion rate can be increased by adjusting the On potentials. Interestingly, the geometry of the coupon was found to have a significant effect on the corrosion rate, emphasizing the importance of current distribution and diffusion processes in the soil. The laboratory investigation was completed with the coulometric oxidation in order to determine the degree of corrosion of the coupons and compare these data with the actual degree of corrosion. The comparison of these data with field results allows the conclusion that the coulometric oxidation not only is useful for the determination of the degree of corrosion on coupons but also to monitor the development of the more general a.c. corrosion situation over time.

INTRODUCTION

The phenomenon "a.c. corrosion" was investigated very detailed since the observation of the first corrosion damages induced by a.c. corrosion on cathodically protected pipelines in the 1988 [1, 2]. Despite of all these investigations, the involved mechanisms are still not completely understood and reliable techniques for the determination of the corrosion risk are not available.

In general, it is well established that the a.c. corrosion can only occur if the a.c. current density exceeds 30 A/m^2 [3-5]. Nevertheless, corrosion attack was also observed on samples with significantly lower current density [6]. This may be caused by the formation of a chalk layer on the coupon surface, which decreases the available surface area and, as a consequence, results in an increased local current density. Moreover, it was found that also high current densities do not necessarily lead to corrosion attack. While the ac-current densities determined on coupons do provide information on the corrosion state, the a.c. potential measured on pipelines was found to be merely an indicator than a criterion. In extended field investigations corrosion attack was found on samples that had less than 5 V a.c. potential [6]. The development of the coulometric oxidation turned out to be a promising technique to determine the amount of a.c. corrosion taking place on coupons. The characterization and analysis of coupons subjected to ac-interference in field applications allowed for evaluating the reliability of the coulometric oxidation in determining the occurrence of ac-corrosion on coupons.

In recent investigations it was demonstrated that the operation parameters of the cathodic protection strongly influence the corrosion rate [7-10]. By running laboratory tests in artificial soil solutions at various cathodic protection levels and evaluating the corrosion rate it was possible to determine their influence on the corrosion rate.

EXPERIMENTAL

For the coulometric oxidation of coupons a Jaissle Potentiostat Galvanostat PCT 1002 in combination with a computer was used. The investigated surface area was 1 cm^2 in all tests. These electrolytes were prepared from reagent grade chemicals and de-ionized water.

Table 1: Composition of the artificial soil solution

	solution with calcium
NaHCO_3	2.5 mmol/l
$\text{NaSO}_4 \cdot 10\text{H}_2\text{O}$	5 mmol/l
NaCl	5 mmol/l

For the simulation of the behavior in soil, coupons were exposed to artificial soil solution in quartz sand. The composition of the electrolyte is given in Table 1. All potentials are referred to saturated Copper/Copper sulfate electrode (CSE).

RESULTS AND DISCUSSION

Based on earlier results it can be assumed that the iron dissolved during anodic polarisation due to ac-interference in alkaline solution is not soluble and is therefore accumulated in front of the coupon [11]. In soil this process is even more pronounced, since the hydrodynamic is more limited. Moreover, the cathodic protection current assures that at least parts of the accumulated iron ions are reduced to Fe(II). Therefore, the amount of accumulated corrosion products in front of the coupon can be determined with the so called coulometric oxidation. The results for coupons exposed to artificial soil solution in quartz sand for seven days under cathodic protection current density of 3 A/m^2 and different ac-currents are shown in Fig. 1. A galvanostatic anodic current load of $100 \mu\text{A/cm}^2$ was applied and the potential development was recorded over time. The sample exposed to 100 A/m^2 showed first some increase in potential, which is followed by a plateau. Based on the results in Fig. 2 it is known that this plateau can be attributed to the oxidation of Fe(II) to Fe(III) [12]. At about 25 mC/cm^2 a steep increase in potential occurs, which stops sharply when the oxygen evolution is occurring. With increasing charge the potential stays almost constant. For the coupon exposed to 0 A/m^2 a similar behavior is observed. The increase of the potential takes place at significantly smaller charge. No corrosion was observed on the coupon exposed to 0 A/m^2 while significant corrosion was observed on the coupon with 100 A/m^2 . Therefore it can be concluded that the position of the increase of potential in Fig. 1 indicates the amount of Fe(II) accumulated in front of the coupon, which is an indicator for the amount of ac-corrosion.

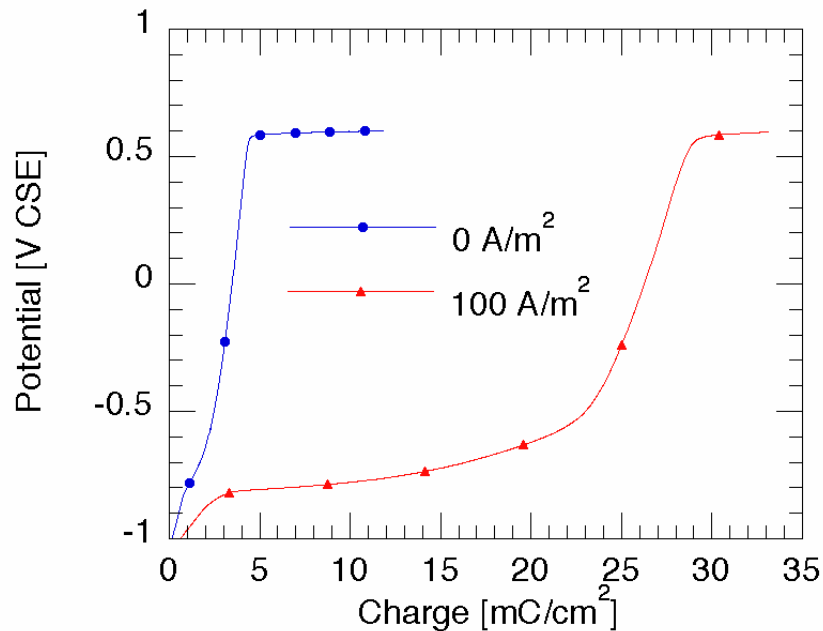


Fig. 1: Coulometric oxidation of coupons polarized for 7 days in artificial soil solutions and quartz sand with 3 A/m^2 and different ac-current densities.

The systematic application of the coulometric oxidation in the control intervals of the cathodic protection of high pressure pipelines in Switzerland allowed collecting the data of the amount of oxidation charge and comparing it to the actual corrosion based on an excavation of the coupons. The results are shown in Fig. 2. A certain correlation between the

charge density determined in coulometric oxidation and the mass loss determined on the coupons can be found. Based on the obtained results an oxidation charge of more than 10 C/cm^2 indicates corrosion attack in the range of one millimeter. In some cases at lower charges, however, the amount of corrosion is underestimated based on the coulometric oxidation. This effect is attributed to an incomplete reduction of the corrosion products due to a low cathodic protection current or the loss of corrosion products during operation. The loss of corrosion products is possible for example as a result of soil settlement. An increased cathodic polarization of the coupon previous to the coulometric oxidation may be useful to ensure the complete reduction of all corrosion products in front of the coupon and exclude the possible insufficient reduction of corrosion products.

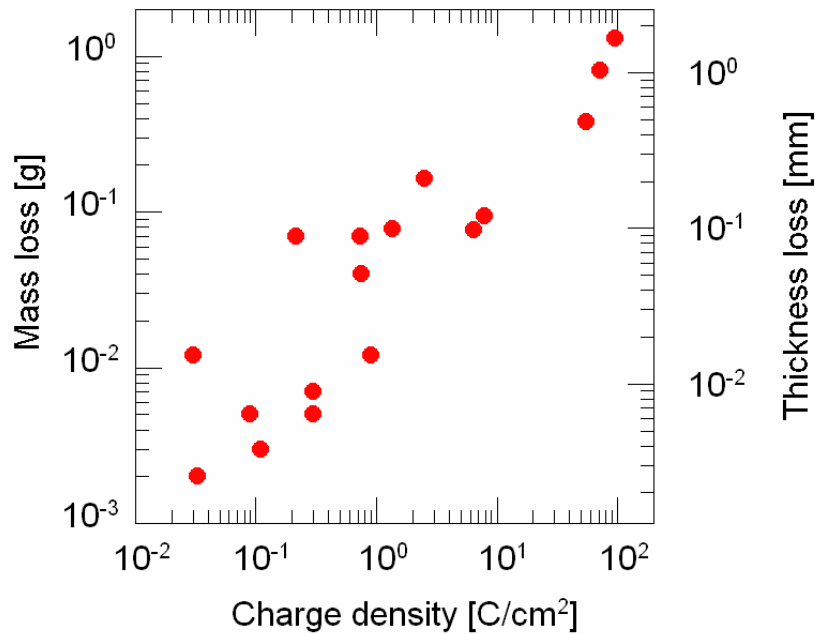


Fig. 2: Comparison of the charge density determined in coulometric oxidation with the mass loss determined after excavation of the coupons. The thickness loss is calculated based on the charge density assuming a homogeneous corrosion attack.

During the coulometric oxidation the Fe(II) in the corrosion products is oxidized to Fe(III). It was found, that a subsequent cathodic reduction of the corrosion products allows for reversible reducing of the Fe(III). In field investigations it was found that the charge determined in coulometric oxidation allows for monitoring of the corrosion situation over time. This is illustrated by the example in Fig. 3. The oxidation of the corrosion products on "coupon a" in 2006 required a comparable amount of charge as the coulometric oxidation in 2003. As a consequence it can be concluded that the amount of corrosion products has not significantly increased within 3 years. On the other hand, the coulometric oxidation on "coupon b" in 2006 required a significantly higher charge for oxidation demonstrating the proceeding corrosion on the coupon. In both cases the On potential was -2.5 V CSE and the Off potential was below -1 V CSE indicating the proper operation of the cathodic protection system. The ac-voltage on the pipeline was below 10 V . The dc current density for coupon a was about 8 A/m^2 and the dc current density for coupon b was 33 A/m^2 . Nevertheless, the coulometric oxidation clearly demonstrates the ongoing corrosion on coupon b. According to Fig. 2 a thickness loss of more than 0.1 mm has to be expected.

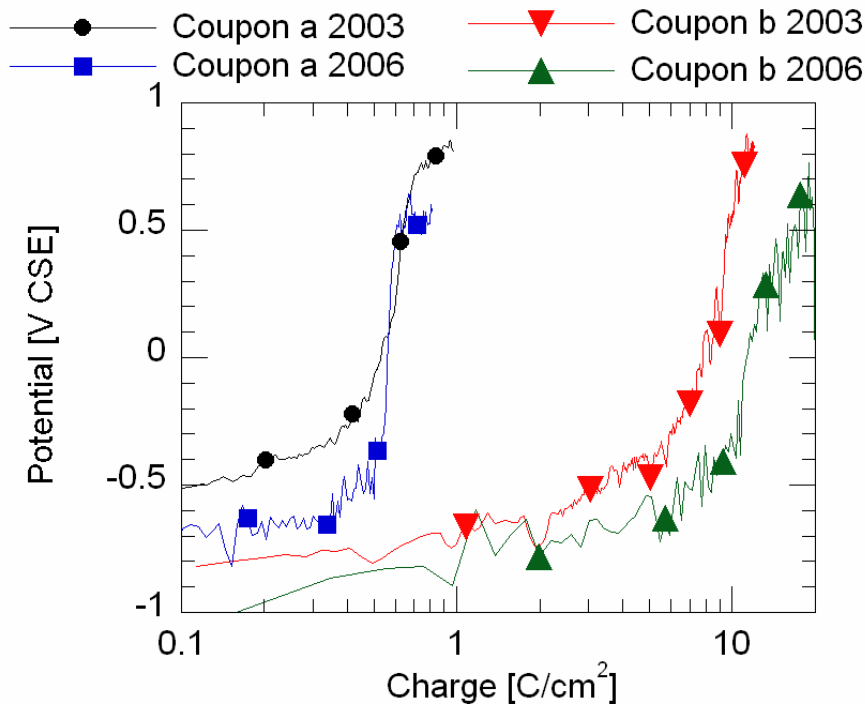


Fig. 3: Coulometric oxidation of coupons connected to a cathodically protected high pressure gas pipeline.

Based on the obtained data the coulometric oxidation allows for estimating the amount of ac-corrosion taking place on coupons. The extended investigations demonstrated the occurrence of ac-corrosion although the ac-voltage was below 10 V. This observation raised doubts whether the further decrease of the voltage is an adequate measure for decreasing the ac-corrosion risk. As a consequence laboratory investigations were performed in order to investigate the effect of cathodic protection parameters on the ac-corrosion rate. These measurements were performed in quartz sand flooded with artificial soil solutions in order to obtain a sufficient reproducibility of the results and exclude the effect of chalk layer formation of the coupons. This artificial soil had a resistivity of 17 Ωm which corresponds to an extremely conductive soil. From the point of view of conductivity the artificial soil may be considered to be a worst case situation. The tests were run at various On potentials of the cathodic protection system and at 14 and 30 V ac-voltage. Furthermore two different sets of coupons of 1 cm² were used. Type one had a remaining coating of 7 mm thickness simulating a punctuation through the coating and the protective cement layer, while type 2 was planar with surface of the surrounding polymer coating simulating an open defect excluding the pore resistance in the coating. Both situations represent extreme cases of coating defects.

The results of the determined corrosion rate compared to the On potential for the coupon type 1 is shown in Fig. 4. Clearly a difference in corrosion rate could be detected between the two a.c. voltages. However, a strong effect of the On potential could be detected as well, confirming the contribution of the cathodic operation parameters to the ac-corrosion rate. Based on the available data a minimal corrosion rate is obtained between On potentials of about -1.2 to -0.9 V CSE. At higher potentials the corrosion rate increases presumably due to an insufficient cathodic protection. However, the increase in corrosion rate at lower potentials is even much stronger. Partly this effect may be due to the decrease in spread resistance caused by the increase of pH at lower cathodic protection potentials.

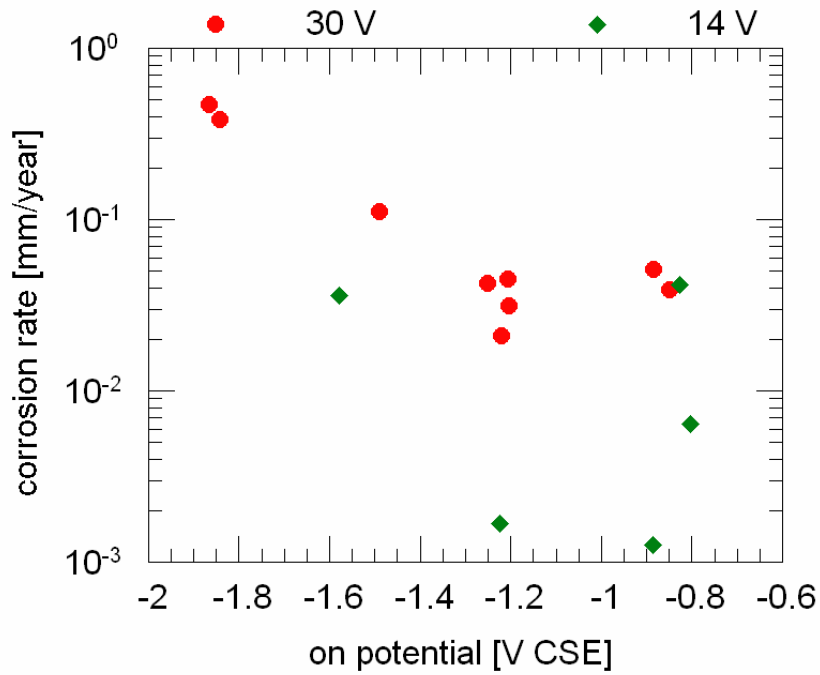


Fig. 4: Corrosion rate of coupons of type 1 at 30 and 14 Va.c. at various On potentials.

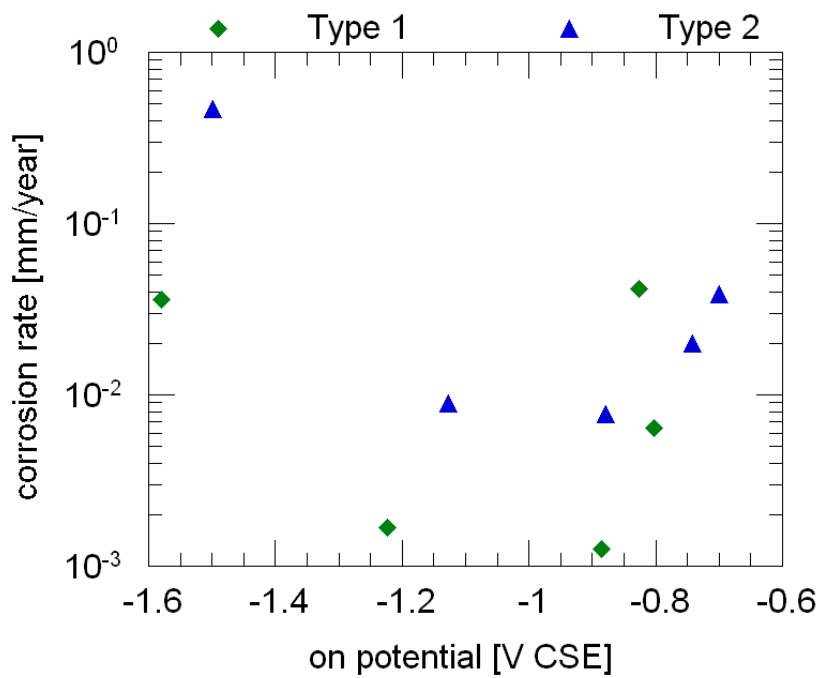


Fig. 5: Corrosion rate of coupons of type 1 and type 2 at 14 Va.c. at various On potentials.

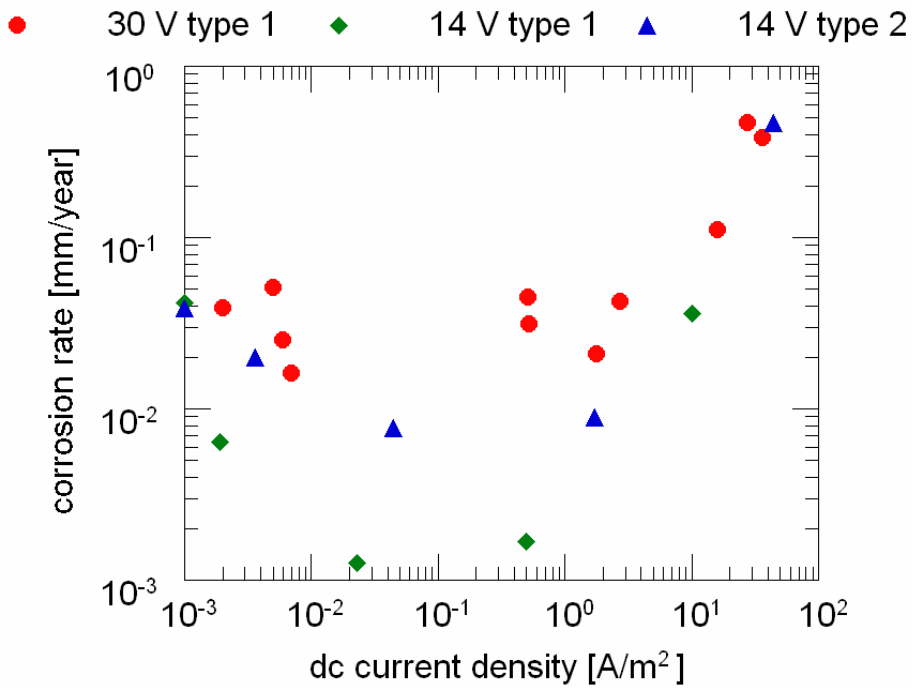


Fig. 6: Corrosion rate of coupons of type 1 and type 2 at 14 and 30 Va.c. plotted vs. the cathodic current density.

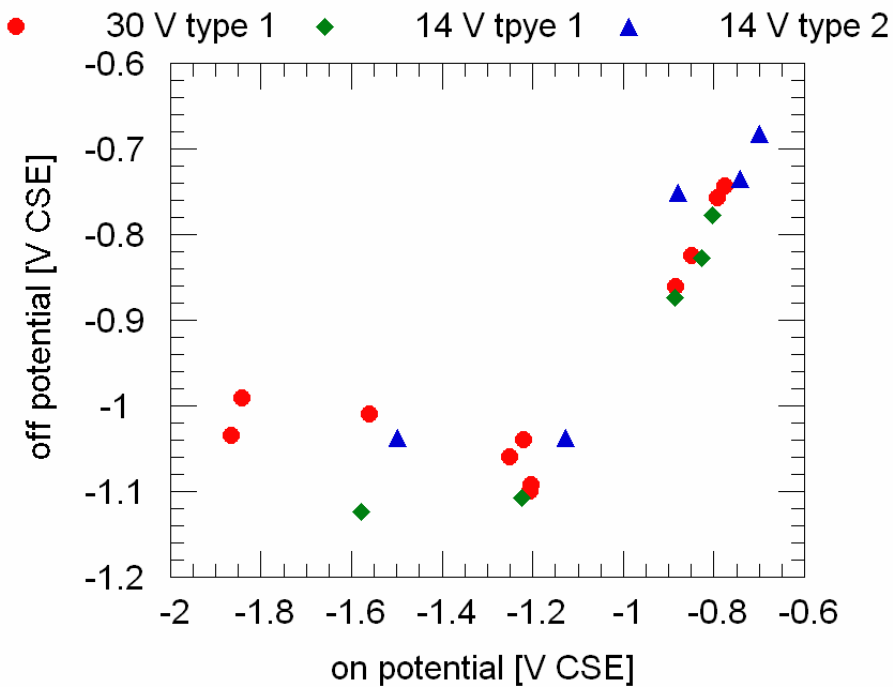


Fig. 7: Off potential compared to the On potential determined on the various coupons.

The effect of the geometry of the coupon is shown in Fig. 5. Apparently the difference in geometry strongly affects the corrosion rate. The strong difference between the two types of coupons at negative potentials may be explained with the increase in cathodic protection current due to the difference in spread resistance. In Fig. 6 the corrosion rate of all investigated coupons is plotted vs. the dc current density. An increasing dc current density

results in increased corrosion rates. It is interesting to note that the difference between the two levels of ac-voltage disappears at sufficiently high dc-current density. This observation is in good agreement with the high corrosion rates observed in field applications at ac-voltages below 10 V and at current densities higher than 10 A/m² shown in Fig. 3.

The obtained data clearly demonstrate the influence of both the a.c. voltage and the cathodic operation conditions. This raises the question how the best condition of the cathodic protected structure can be experimentally determined. Based on the results in Fig. 4-6 this could be possible based on the on-potential or the dc-current density. Unfortunately the dc-current density can only be determined on coupons and the On potential is expected to depend on the soil resistivity. The Off potential corresponding to the investigated coupons is shown in Fig. 7. It is clear, that the Off potential does not indicate the presence of a high cathodic current density. The obtained data indicate that the Off potential stays constant independent on the cathodic current density as soon as the hydrogen evolution is reached. As a consequence it must be concluded that the On potential is the most reliable indicator for the presence of an optimal protection condition. In the present investigation a worst case situation was investigated, since the soil resistivity was chosen to be extremely low. In practical applications however, it is expected that the on-potential of -1.2 V CSE is not necessarily sufficient to obtain a proper protection of the pipeline against corrosion. Especially in high resistivity soils or on pipelines with a poor coating quality an Off potential of -0.85 may be difficult to reach. Yet it may be concluded from the present results that a pipeline with an On potential of -1.2 V CSE and an a.c. voltage of less than 15 V is not expected to exhibit a corrosion rate of more than 0.01 mm/year.

CONCLUSIONS

The field investigations of coupons with the coulometric oxidation demonstrate the correlation between the actual corrosion and also the applicability of the method for monitoring the progress of the corrosion over time. The corrosion attack may be underestimated if the corrosion products are not sufficiently reduced or if they are not electrochemically accessible. The problem with insufficient reduction of the corrosion products can be solved by applying a reduction current on the coupon prior to the coulometric oxidation. Based on the collected data a charge density required for oxidation that is exceeding 10 C/cm² indicates severe corrosion of more than 0.1 mm.

The laboratory investigation of a.c. corrosion in artificial soil clearly demonstrates the strong effect of the On potential on the corrosion rate. At high protection current densities obtained at negative On potentials the effect of the corrosion rate is higher than 0.1 mm/year and the effect of a.c. voltage level is negligible. Even at low a.c. voltage high corrosion rates may be observed. This conclusion allows explaining the severe corrosion observed in field applications even at ac-voltage below 10 V. Hence the cathodic protection parameters have to be optimized in order to minimize the a.c. corrosion rate. Unfortunately the presence of an optimized protection condition can only be determined by means of coupons. The dc current density must be below 5 A/m² in order to significantly decrease the corrosion rate. Presumably even lower current densities are desirable.

The geometry of the coupon has a significant effect on the a.c. corrosion rate. Small spread resistance can result in significantly increased corrosion rate.

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