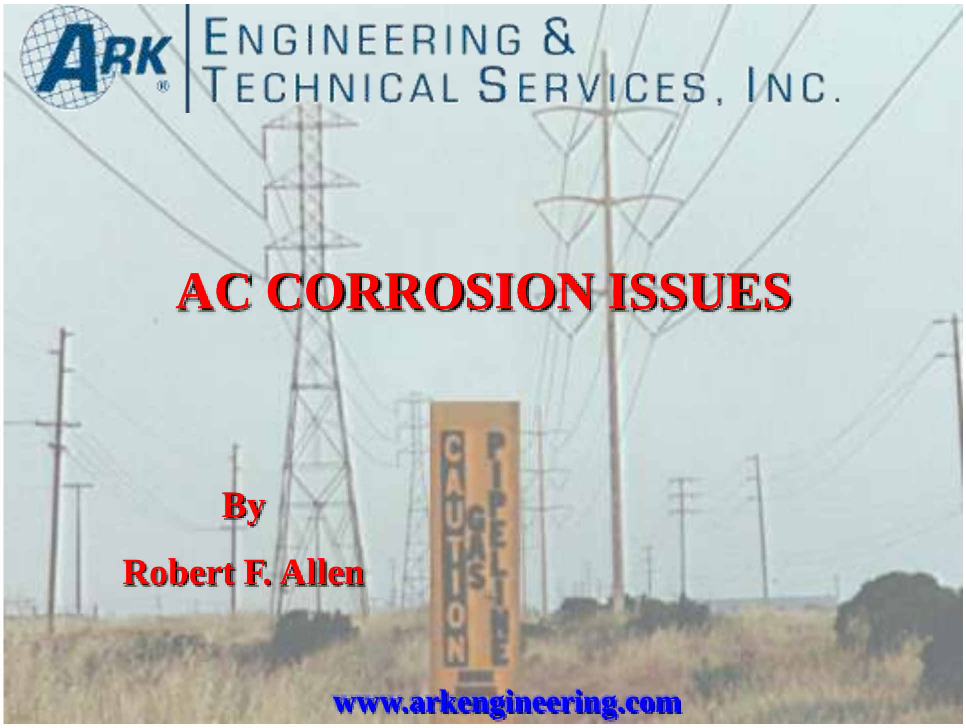
ENGINEERING &
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AC CORROSION ISSUES
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Introduction

- Corrosion effects to pipelines by induced AC currents continues to be a controversial subject.
- In the past 20 years, AC Corrosion effects has been recognized as a real threat to pipeline integrity.
- Overview of the issues surrounding AC Corrosion effects.

Overview

- In 2007, NACE - Task Group 327 completed a State-of-the-art paper. "AC Corrosion State-of-the-Art: Corrosion Rate, Mechanism, and Mitigation Requirements"
- The paper's purpose was to set the stage for subsequent development of CP criteria for AC Corrosion
- It describes the currently used approaches for protection and monitoring.

State-of-the-Art Report

- The technical committee's report represents the current understanding of the AC Corrosion phenomenon associated with AC interference on buried steel pipelines.
- The report addresses AC Corrosion characteristics and proposed mechanisms, and describes current approaches to protection and monitoring.

Overview

- Induced AC voltage may be a cause of corrosion at coating defects where AC current escapes the pipe.
- Small rather than large coating defects are susceptible to AC corrosion since the spread resistance (in Ω-m^2) associated with the defects increases with increasing area

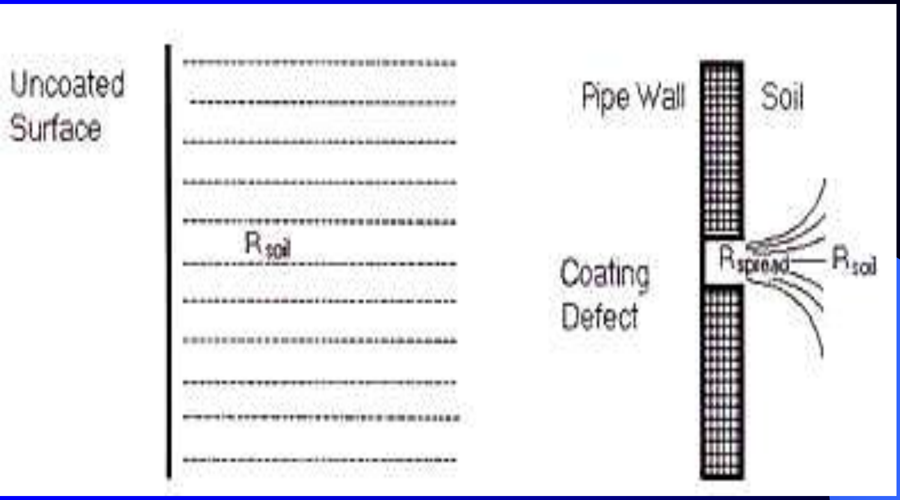
Spread Resistance

- The spread resistance R_S is controlled by factors relating to the resistance of the soil, porosity, and geometric factors in the interface between the soil and the coating defect.

Spread Resistance

- A non-coated surface results in only a soil resistance value.
- A coated surface with a defect results in both soil resistance and spreading resistance values. A large IR drop develops near the vicinity of the pipe to soil interface where the coating defect is present.
- A geometrical spread effect is produced as a result of concentrated current flux lines.

Spread Resistance



Spread Resistance Calculations

- $R_s = K \rho_s d \quad (\Omega\text{-m}^2)$
- K – constant, based on the geometry of the defect
- ρ_s – specific resistivity of the local soil adjacent to the defect
- d – measure of the extension of the defect

Effect of Surface Area

- The surface area of the pipe at a coating holiday is important since the corrosion rate increases with increasing current density.
- Large holidays would have a lower current density than small holidays if both were exposed to the same soil conditions.

AC Corrosion Research

- Laboratory and Field tests using 10 cm^2 coupons in soils subject to AC current densities of 50 and 100 A/m^2 resulted in a test coupon being perforated after 168 days at an AC current density of 100 A/m^2
- Field inspections found 42 mils pits after 2.5 years of pipeline operation in 20,000 ohm-cm sandy soil at AC current densities of 74 – 165 A/m^2

Research Studies

- AC Voltage required to produce a current density of $100 A/m^2$ in 1000 ohm-cm soil at a $1\ cm^2$ holiday:
- $i_{ac} = 8\ V_{ac} / \rho\ \pi\ d$
- Where:

i_{ac} = ac current density (A/m^2)

V_{ac} = pipe ac voltage to remote earth (V)

ρ = soil resistivity (ohm-m)

Research Studies

- d = diameter of a circular holiday having a $1\ cm^2$ surface area = 0.0113 m

Then: for $i_{ac} = 100 A/m^2$ and $\rho = 10$ ohm-m

$$V_{ac} = \frac{100 A/m^2 \cdot 10\ \text{ohm-m} \cdot 3.14 \cdot 0.0113 m}{8}$$

$V_{ac} = 4.4$ V

Results

- The calculation indicates that CP protected pipelines subjected to AC voltages that are below the NACE recommended maximum safe level of 15 volts (NACE SP0177) can suffer from AC corrosion at holiday sites having a surface area of approximately 1 cm^2 in a soil resistivity of 3000 ohm-cm or less.

Research Study

- Laboratory based studies to determine:
- The effects of AC current density on the corrosion rate
- Cathodic Polarization requirements necessary to mitigate the impact of AC current

Research Study

- Testing carbon steel specimens exposed to soil
- AC current was passed between specimens
- A closely placed $Cu/CuSO_4$ reference electrode measured on & off potentials
- The targeted experimental variable were:

Research Study

- AC target current density:
  20 A/m^2 (Low)
  500 A/m^2 (High)
- CP target potential shift:
  0 mV (No CP)
  100 mV (Low)
  300 mV (High)

Research Results

- The presented results indicate that $100 A/m^2$ is large enough to cause significant corrosion attack.
- The majority of the studies indicated that AC corrosion is possible at current densities between 20 to $30 A/m^2$.

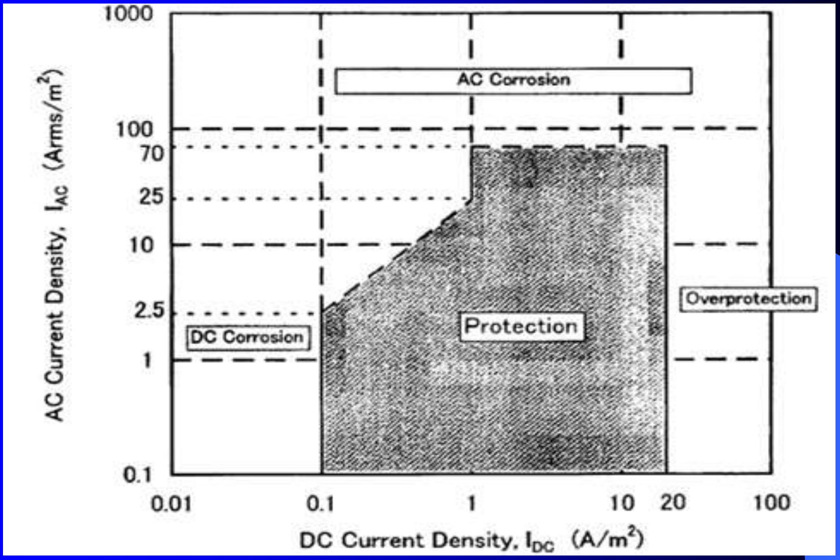
Conclusions

- Data presented indicates that corrosion can be enhanced at an AC current density of $20 A/m^2$: but CP can be effective in mitigating corrosion, although an increase in polarization level (150 to 200mV) may be necessary.
- At an AC current density of $20 A/m^2$, CP of 100-150mV polarization, decreased corrosion rate compared to no AC, no CP:
- Additional CP to 250 - 300mV polarization decreased the corrosion rate even further.

AC Corrosion Risks

- The following factors increase AC corrosion risks:
- A low level of cathodic protection (low current density) with a high level of AC current density
- Small size coating defects
- Low soil resistivity

AC and DC current density relationship to achieve protection



Ratio Between AC & CP Currents

- I_{AC} / I_{DC} is less than 5 – AC Corrosion likelihood is low
- I_{AC} / I_{DC} is between 5 & 10 – AC corrosion likelihood can exist
- I_{AC} / I_{DC} is greater than 10 – High AC Corrosion likelihood (Mitigation measures required.

CP Effectiveness Threshold

- CP ‘effectiveness threshold’ in the presence of AC currents, Suggests that that if AC current density is in excess of a certain value (over 70 A/m^2 in the quoted study), CP is not likely to have an effect unless the AC levels are reduced below the ‘threshold’ at which CP can mitigate corrosion.

European Standard CEN/TS 15280

- The pipeline is considered protected from AC corrosion if the RMS AC current density is lower than 30 A/m^2
- Less than 30A/m^2 – No or low likelihood
- Greater than 30A/m^2 but less than 100 A/m^2 – Medium likelihood
- Greater than 100A/m^2 – Very high likelihood

Case Studies from NACE Papers

- Case studies of suspected AC corrosion and guidelines on how to assess whether a pipeline is susceptible to AC corrosion will be discussed.

Pipeline Failure in Germany

- In 1986 - 2 perforations occurred on a polyethylene coated pipe installed in 1980 parallel to a 16.6 Hz AC powered rail system at a road crossing.
- CP potentials were –1000 mV_{cse} and corrosion product pH was 10.
- CP system was operating adequately to industry standards.

Pipeline Failure in Germany

- Excavation revealed “crater-like” corrosion pits underneath corrosion product “bulges”.
- Low soil resistivity (1900 ohm-cm) was attributed to de-icing salt contamination.
- A steel rod coupon was installed and monitored for 220 days.

German Research Data

- The coupon had a holiday surface area of 1 cm^2
- Despite a CP current density of 1.5 to 2 A/m^2 and an “ON” potential of -1800 to -2000 mV_{cse} ,the coupon exhibited pitting corrosion at a rate of 210 mpy due to an AC current density which varied from 20 to 220 A/m^2

Recommendations

- Monitoring the current density rather than just AC voltages is crucial to assessing the AC current-related corrosion hazards to a buried pipeline
- Monitoring of the AC current density may be accomplished by installing coupon test stations (CTS) along the affected structure
- The mitigation criteria should put the emphasis on mitigating the AC current density, rather than just the AC voltage.

Case Study

- An external corrosion failure of an 11 year old natural gas pipeline.
- The pipeline exhibited high levels of AC due to parallelism with high voltage power lines.
- The failure occurred at a location of peak AC voltage.

Case Study Specifications

- 12” diameter, (0.25” w.t.), coated with extruded polyethylene with CP.
- 1” diameter smooth, round, dish shaped pit
- CP records indicate a well protected line
- Pipeline parallels 4-345 kV & 1-115 kV circuits for over 5 miles.
- Induced AC potentials of 50-80 V

Conclusions

- An anode bed in the area of the failure was found to be disconnected.
- No evidence of any DC stray current interference affecting the pipe
- The coating holiday was approx. 0.5” and pipe AC voltage was approx. 50 Volts
- Soil resistivity was measured at 16 Ω-m

AC Current Density Calc.

- AC current density at the holiday was calculated to be 800 A/m^2
- This is well above the criteria for AC corrosion discussed previously

Soil Resistivities

- The soil resistivities measured in the excavation were significantly lower than the bulk resistivities measured along the pipeline using the Wenner 4-Pin Method
- This was attributed to the moderately high chloride ion content of the soil, presumably due to the application of. de-icing salts to the roadway during the winter months.

Conclusions

- To overcome the effects of the AC currents, the current needs to be mitigated first.
- Mitigation of AC potentials to values below 15 Volts may not be sufficient with respect to AC current densities at the coating holidays.

Recommendations

- An AC mitigation system was designed to reduce the steady-state AC voltages to levels that would minimize the risk of subsequent AC corrosion damage.

Other Factors

- Mitigation wire provides a benefit in the mitigation of AC corrosion. For a coating holiday located in the vicinity of the mitigation wire, the effective resistance of the holiday is increased due to the mutual resistance between the holiday and the mitigation wire, thereby reducing the AC current density at the the holiday.

Case Study No. 2

- In 2002, an 8” diameter (0.188 w.t.) liquid pipeline with FBE coating and CP experienced a leak.
- Pipeline was installed in 1999 with FBE coating
- The leak was caused by a 1” x 2” corrosion pit

Case Study No. 2

- Inspection of the defect revealed an isolated smooth round corrosion pit that was uncharacteristic of either microbial influenced corrosion or DC stray current corrosion
- A corrosion rate of 60 mpy was calculated

Case Study No. 2

- 27 external coupons were installed on the pipeline, at one mile intervals to measure the DC potentials, AC potentials, and current densities.
- The coupons provide the necessary data to assess the likelihood that AC interference is contributing to the observed corrosion.

Conclusions

- AC current densities measured at the coupon test stations exceeded cited levels that typically produce corrosive effects
- Three (3) of the sites tested have AC current densities in excess of 100A/m^2

Corrosion Rates

- A literature study concluded that corrosion rates in the presence of AC:
- Increased in chloride containing or deaerated environments
- Increased with decreasing AC frequency (under 100 Hz)
- Increased with decreasing holiday surface area
- Decreased with increasing CP current density and time

Indications of AC Corrosion

- The approach is to eliminate all other culprits (such as microbiologically influenced corrosion (MIC), and evaluate the characteristics of the corrosion (pit has rounded bottom, corrosion product formed a hard dome over the pit)

AC Corrosion Monitoring

- AC Current density appears to be a reliable measurable parameter related to AC corrosion rather than just induced AC voltage.
- Coupon test stations can be used to measure AC current density and not just current flow in the ground.
- This approach is capable of determining a means to estimate AC current density on the pipeline at a particular location.

Conclusion

- Research is on-going to determine the mechanisms of AC corrosion.
- The NACE AC Corrosion Task Group – TG37, will approve and publish this state-of-the-art report and work toward publishing an RP on AC Corrosion test methods.
- European Standard CEN/TS 15280:2006 is available with guidelines for AC corrosion risk assessment.

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