Evaluating Corrosion Mechanisms with Extended Coupon Analysis

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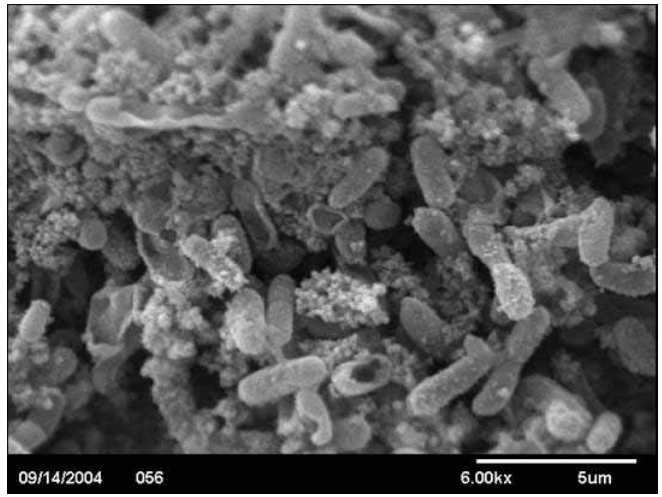
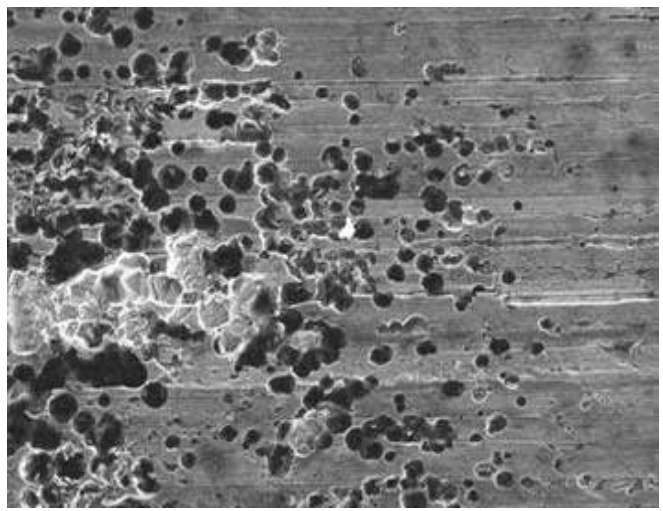
Agenda





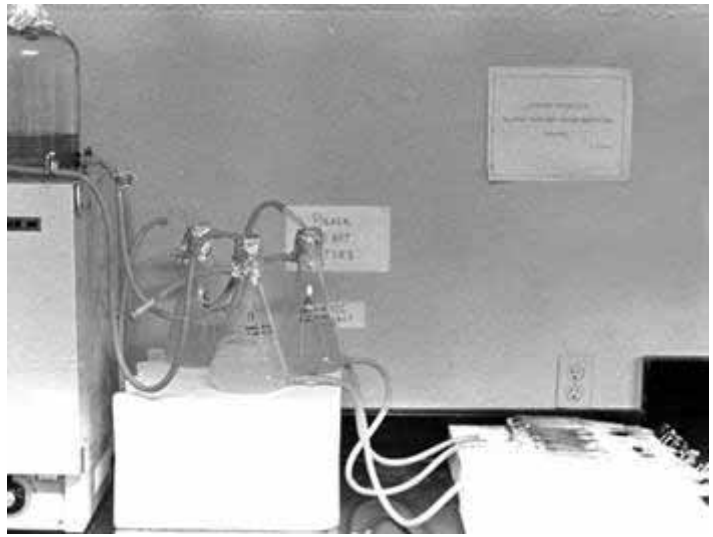
- Research and Development
- Field Application
- Extended Analysis
- Case Study

Origins…

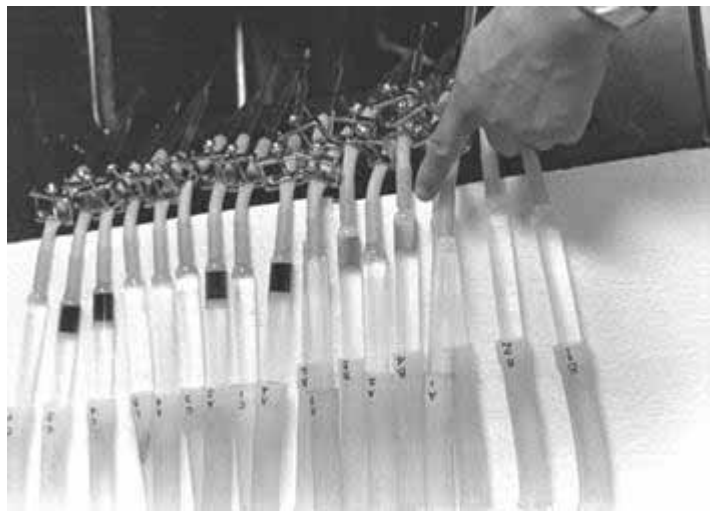
- **Roots in the Microbiologically Influenced Corrosion research from GRI (1988)**
- **Input from microbiology and corrosion experts in academia and industry.**
- **Technique has been reported in numerous publications, symposia, technical papers, and a PRCI study in 2006.**

Research and Development

GRI-MIC group pipeline research in 1988-89.



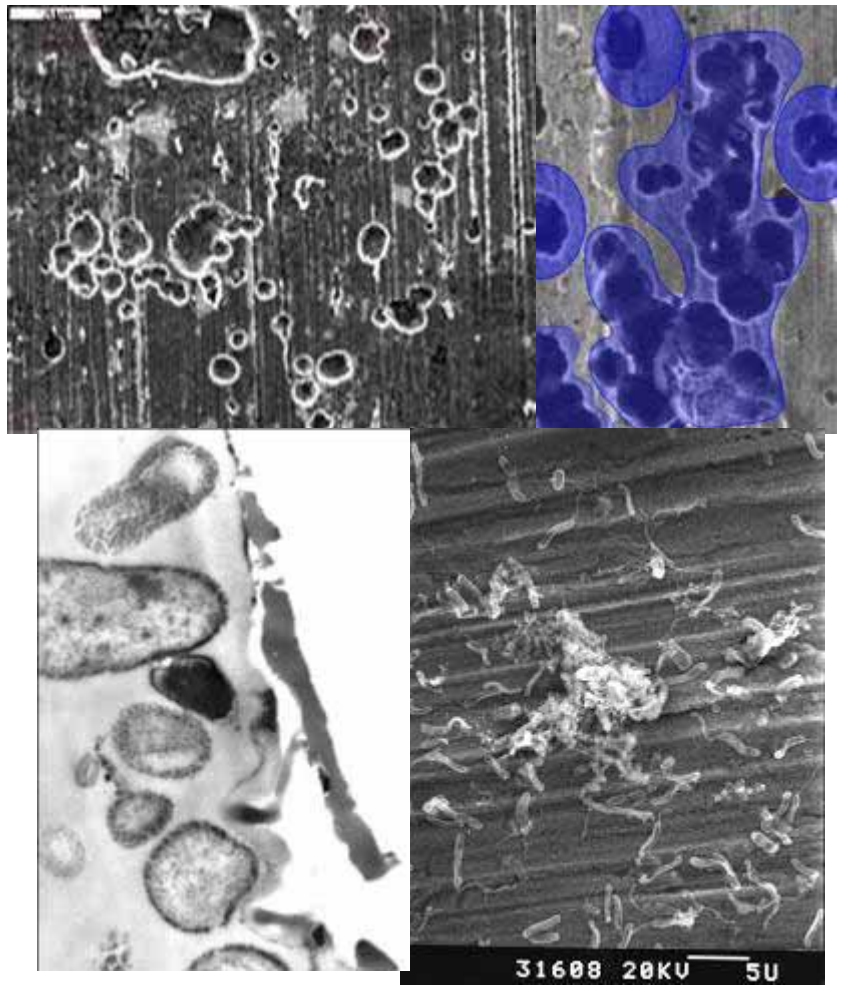
Pipeline steel coupons were exposed in a model system containing *Enterobacter aerogenes*, *Clostridium acetobutylicum* and *Desulfovibrio desulfuricans*.



Research and Development

After various exposure periods, the coupons were preserved, embedded and examined using phase contrast and UV fluorescence microscopy, transmission electron microscopy and scanning electron microscopy.

Corrosion and biofilm were mapped using various techniques.

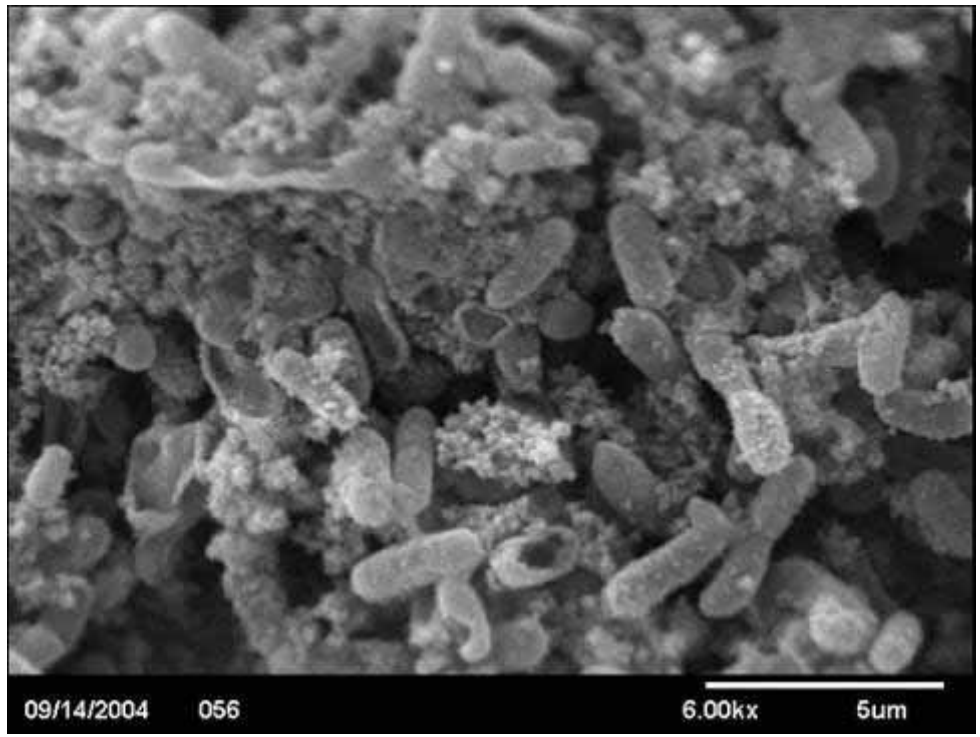


Research - Conclusions

- Bacterial colonization on pipeline steels directly correlated with initiation and growth of biotic corrosion pits.
- Biotic pits on the steel surface physically matched with bacteria embedded in plastic replicas.
- Biotic pits from microbial activity initiated on pipeline steel within a few hours.
- Biotic pits initially the same size as bacteria (or colony).
- Biotic pits grow/ merge to form large, irregularly shaped pits.

Research - Conclusions

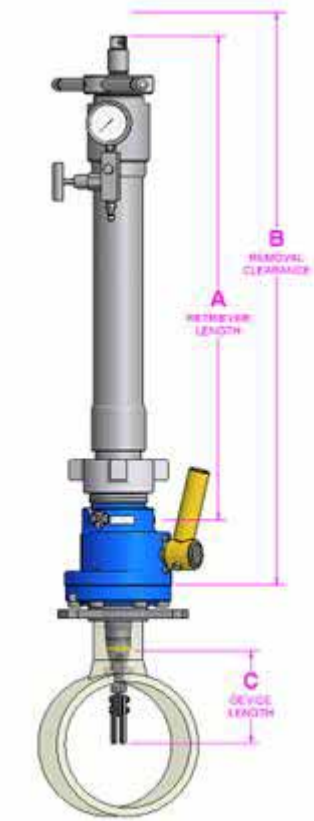
- As biotic initiated pits grew and coalesced, the characteristic morphology disappeared.
- Microscopic pit initiation morphology from MIC in the field is similar to that observed in the laboratory on pipeline steels.
- Gained ability to discern between “biotic” and “abiotic” corrosion initiation.

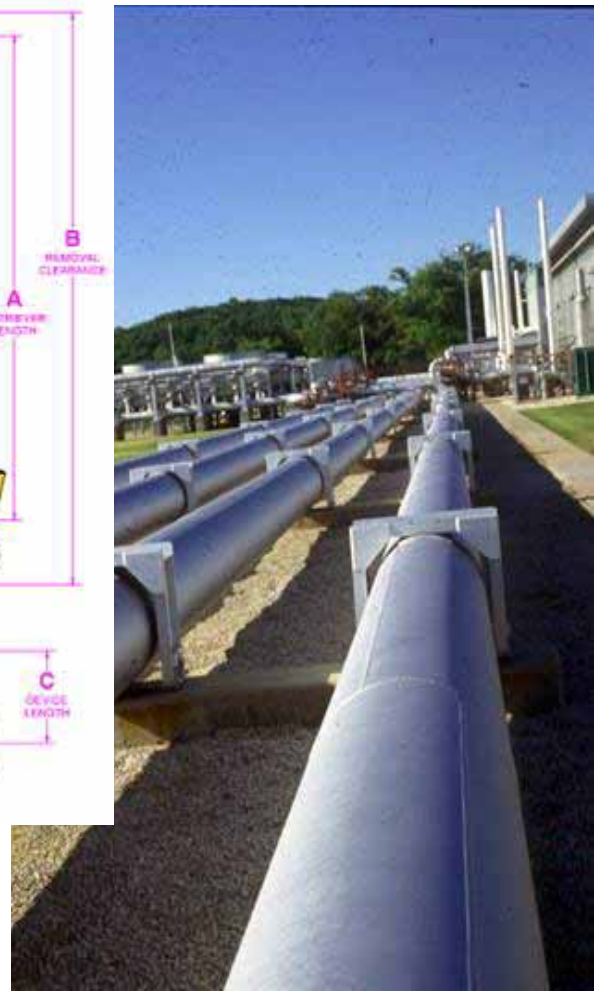


Field Application…

Extended analysis coupons (EM coupons) are exposed to process fluids in the same manner as weight loss coupons

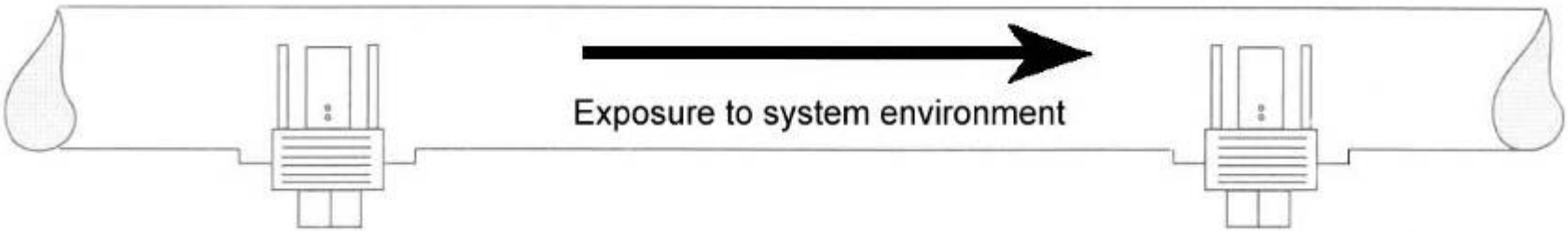
After exposure, special handling and preservation are required to preserve biofilm and corrosion products



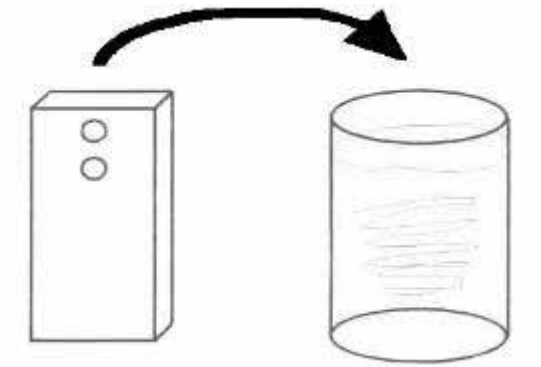


Exposure and Handling

Coupons are installed using typical access fittings and exposed to process fluids. Exposure depends on overall corrosivity of the fluid.

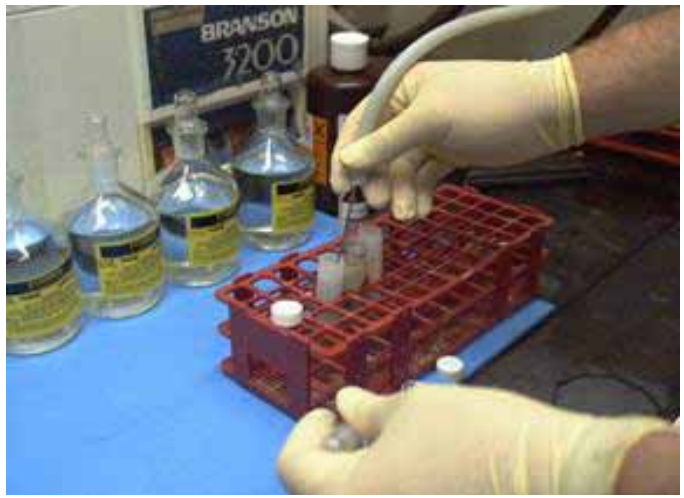


Immediately upon removal, coupons are placed into vials of anaerobic holding solution for temporary handling, shipment and subsequent preservation.

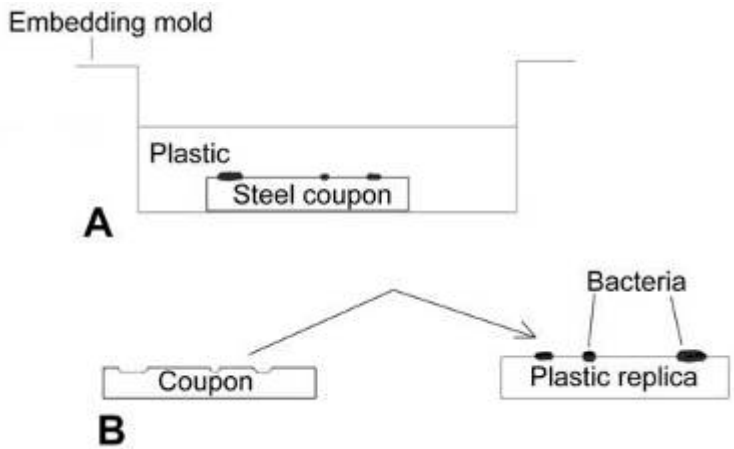


Preservation

Within 24 hours of removal, the coupons are fixed in 2% glutaraldehyde, rinsed and dehydrated using an ethanol series. The coupons are then embedded in an acrylic resin.

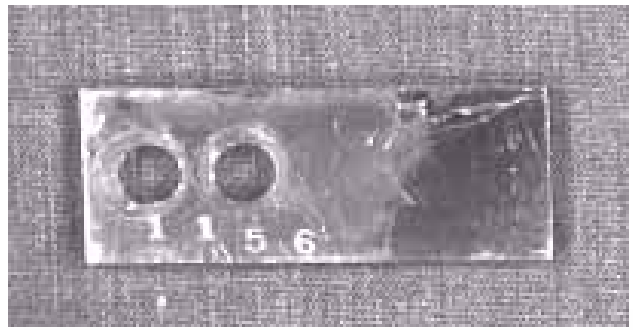


The acrylic “replica” is subsequently removed with the biolfilm/corrosion product embedded, and the coupon is cleaned with acetone.



Why Extended Analysis?

While not always evident via visual inspection, microscopic corrosion initiation can be occurring on coupons.



By the time severe damage is observed on a coupon, mitigation becomes reactive instead of proactive.

Detection and identification of initiating pits is possible using microscopy; this can be important in the avoidance of advanced corrosion.

Optical Microscopy

Coupons examined using a stereomicroscope, typically at 10x and 40x.

The pit density, maximum depth, and maximum diameter of pitting are measured.

The corrosion type and the corrosion severity are noted and recorded using a standardized grading.

Optical exam provides an overall perspective on corrosion severity, morphology and distribution.

Optical Microscopy Results

- Average Pit Density: number of pits per square centimeter (cm^2)
- Corrosion Rate: expressed in mils per year (mpy)
- Max Depth: depth in microns from the deepest pit located
- Max Diameter: diameter in millimeters from the largest pit located
- Optical Severity: categorization, on a macro scale of the corrosion observed
- Optical Type: categorization, on a macro scale of the corrosion observed
- Pit Rate: pitting rate is calculated using the maximum pit depth

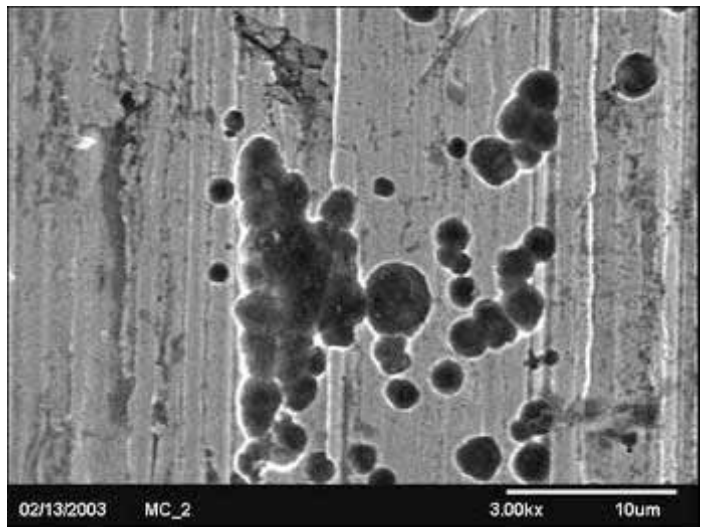
- Note: Standard mass loss is also performed

SEM Examination

SEM exam of coupon is performed for identification of pit initiation morphology.

SEM exam also identifies -

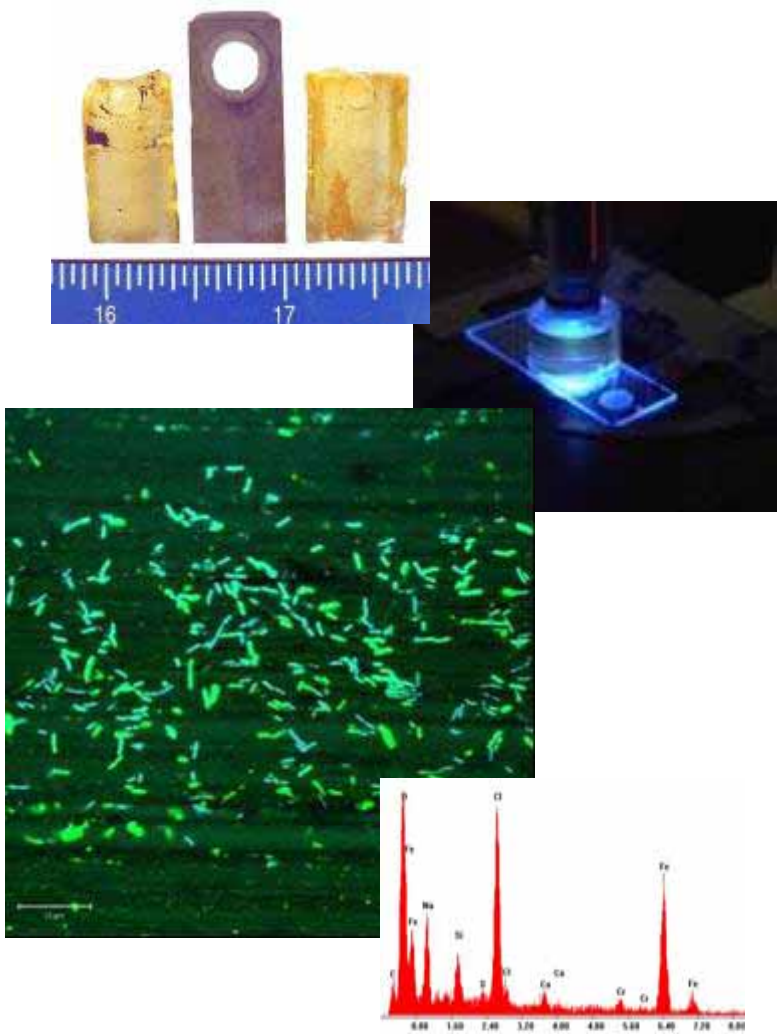
- Relationships between initiating and advanced pits/corrosion.
- Spatial correlation between actual corrosion on coupon and deposits/biofilm on replica.
- Potential significance of scale in relation to corrosion damage.



SEM Results

- SEM Severity: categorization, on a micro scale, of the severity of corrosion observed
- SEM Type: categorization, on a micro scale, of the type of corrosion observed, such as pitting or etching
- SEM Pit Type: classification associated with the predominant pit initiation mechanism, biotic or abiotic
- Scale Morphology: when scale is present a physical description is provided

Replica Exam

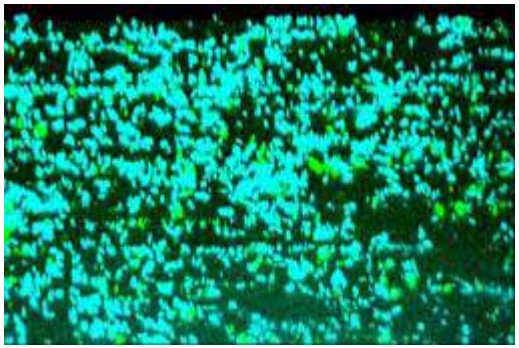


Embedment preserves biotic and abiotic material associated with the coupon surface.

Not necessary to perform analysis of the embedment to confirm biotic pitting.

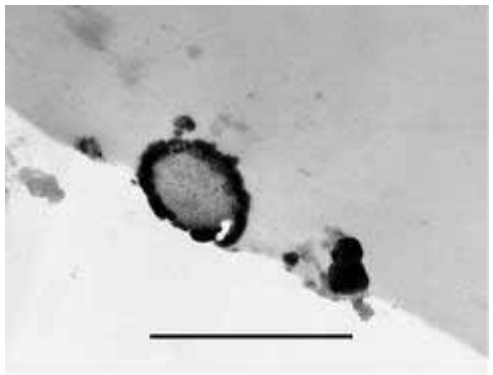
Additional analyses can be performed on the embedment, such as EDS of corrosion products or deposits, and specific bacteriological staining protocols.

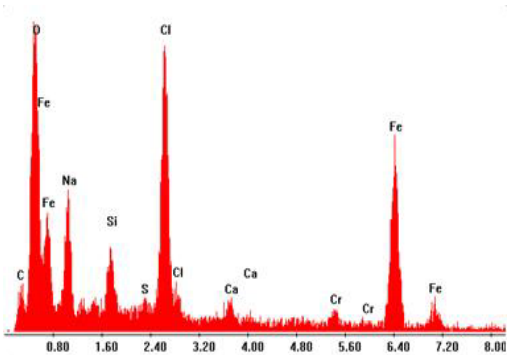
Replica Exam Options



Epifluorescent and phase contrast microscopy relate bacteria to corrosion on the coupon; staining protocols used to identify specific bacteria types

TEM – Transmission Electron Microscopy can identify bacteria using genetic probes; examine corrosion products associated with specific cells





EDS – Energy Dispersive Spectroscopy; qualitative elemental identification of deposits

Case Study - Summary

Based on a published study of two offshore natural gas/liquid gathering systems, the following observations were made based on the use of Extended Analysis coupons:

- Microscopic analyses of coupons can indicate subtle localized attack due to bacteria (“biotic” attack), conventional electrochemical (“abiotic”) corrosion, and mechanical mechanisms (erosion); this data can indicate the need to apply mitigation measures - before significant corrosion can occur.

- The efficacy of biocides or corrosion inhibitors can be comprehensively evaluated using extended analysis coupons, and the use of mitigation targeted toward the dominant corrosion initiation mechanism.

- Application of extended analysis coupons resulted in significant cost savings and a reduction in corrosion leaks in the gathering systems evaluated.

References

- Richard Eckert, Henry Aldrich, and Chris Edwards, B. A. Cookingham, “Microscopic Differentiation of Internal Corrosion Initiation Mechanisms in a Natural Gas System,” *Paper No. 03544* presented at CORROSION/03 San Diego, CA.

- T. P. Zintel, D. Kostuck, and B. A. Cookingham, “Evaluation of Chemical Treatments in Natural Gas System vs. MIC and Other Forms of Internal Corrosion Using Carbon Steel Coupons,” *Paper No. 03574* presented at CORROSION/03 San Diego, CA.

- Richard Eckert, Henry Aldrich, and Bruce G. Pound, “Biotic Pit Initiation of Pipeline Steel in the Presence of Sulfate Reducing Bacteria,” *Paper No. 04590* presented at CORROSION/04 New Orleans, LA.

- Richard Eckert, Henry Aldrich, Clinton Yang and Chris Edwards, “Guidelines for Reproducing Microbiologically Influenced Corrosion Initiation on Carbon Steel Under Controlled Conditions,” *Paper No. 06519* presented at CORROSION/06 San Diego, CA.