The use of split-chambe zero resistance ammetry measurements to evaluate microbially influenced corrosion in gas and hazardous fluid transport pipelines

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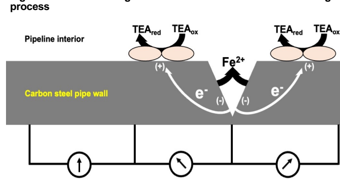
Background – the split chamber zero resistance ammetry (SC-ZRA) technique

Microbially influenced corrosion

The activities of microorganisms can induce corrosion

This typically occurs when their activities induce the development of localized anodic and cathodic regions of a metal surface (Figure 1)

Figure 1. Schematic diagram of MIC activities and ZRA monitoring process

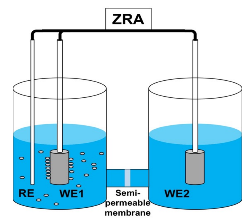


Challenges

Detecting µm-scale processes in m-km-scale settings

Diversity of microbial metabolisms that can cause corrosion

Figure 2. Schematic diagram of SC-ZRA setup



The split chamber zero reisistance ammetry technique

Involves monitoring of current between two carbon steel electrodes (Figure 2)

Localized anodic and cathodic regions of metal surface are mimicked in this setup

Different biological and chemical conditions can be mimicked in SC-ZRA setup

Allows us to monitor microscale processes at mesoscale

May be used to monitor MIC by detecting current between discrete portions of pipeline (Figure 1)

Using SC-ZRA to evaluate sulfate reducing bacterially induced corrosion

Sulfate reducing bacteria (SRB) and corrosion

SRB can cause corrosion by directly consuming electrons from metals (called electrical MIC; EMIC) or by producing corrosive metabolites (called chemical MIC; CMIC)

We sought to determine if the SC-ZRA approach could reliably detect corrosion by SRB

Approach

A sulfate reducing bacterial enrichment culture was added to the WE1 side of SC-ZRA incubations, while the WE2 side was left uninoculated (Figure 2)

This setup mimics the heterogeneous metal surface coverage that can lead to corrosion (Figure 1).

Current and potential measurements were collected and where appropriate, sulfate and lactate measurements were made.

Uninoculated and chemical controls were included.

Results

No current was observed in uninoculated SC-ZRA incubations, and the corrosion rate on both coupons was the same.

When lactate was included, was initially positive, then negative. Negative current is consistent with Scenarios 1 and 2 and with corrosion rates observed on the respective coupons.

When lactate was omitted, current was consistently negative, which is consistent with Scenario 2 and with corrosion rates observed on the respective coupons.

When only sulfide was added, current was consistently negative, which is consistent with Scenario 3 and with corrosion rates observed on the respective coupons.

These results indicate that the activities of SRB can be detected using ZRA measurements and can reliably indicate corrosive activities

Figure 3. Current, potential, and analysis of metabolic indicators in SC-ZRA incubations with SRB

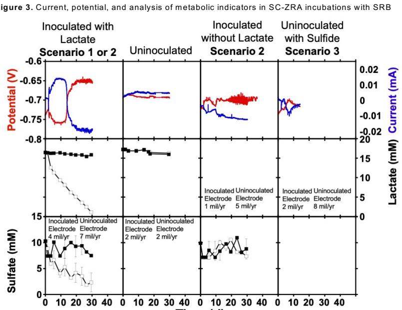
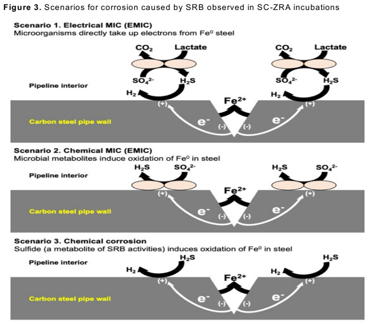


Figure 3. Scenarios for corrosion caused by SRB observed in SC-ZRA incubations



Application of SC-ZRA to diverse corrosive metabolisms

Bacterial enrichment cultures

Bacterial enrichment cultures with a variety of potentially corrosive metabolisms were obtained from pipeline pigging sludge (Figure 5)

Enrichments were incubated under a variety of conditions that could enhance or inhibit their corrosive activities:

1) The fermentative enrichment culture was incubated with or without bicarbonate for pH control
2) The SRB enrichment culture was incubated with or without lactate as an electron donor
3) The lactate and Fe0 oxidizing thiosulfate reducing enrichment cultures were incubated with or without lactate as an electron donor
4) The thiol metabolizing enrichment culture was incubated with or without cysteine as an S source and with or without acetate as a carbon source.

Applicability of SC-ZRA to detecting corrosion

Differing microbial enrichment cultures yielded different patterns of current and potential (Figure 6).

When extensive current production was observed, mass loss from coupons was observed.

The direction of current was indicative of which coupon suffered the most corrosion, indicating that the technique can be used to localize corrosion.

SC-ZRA might be used to
1) Detect MIC
2) Localize MIC
3) Identify causative metabolism

Figure 5. Metabolisms targeted in enrichment cultures and composition of the cultures. Colored boxes indicate shading of current and potential plots in Figure 6

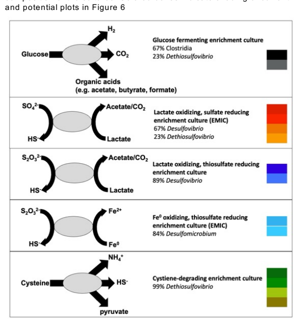


Figure 6. Current and potential in SC-ZRA incubations with a variety of potentially corrosive microbial metabolisms