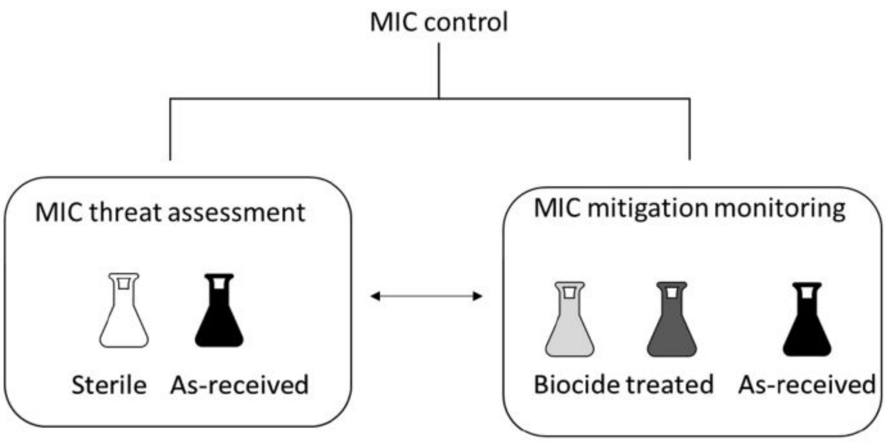

FIGURE 2 Conceptual design of laboratory test method for MIC control.

mitigation (chemical and/or concentration) on microorganisms, the chemical and physical environment, and the corrosion products that form. Based on the situation, the impact of the chemical addition can be determined, either on biofilm and MIC prevention or biofilm and MIC mitigation. For investigating biofilm and MIC prevention, chemically treated and untreated fluids can be incubated with metal coupons and the changes to the biofilms and planktonic microbial populations (abundance, diversity, and activity), corrosion/pitting rates, and corrosion products can be monitored throughout the duration of testing. For investigating biofilm and MIC mitigation, process fluids can be first incubated with metal coupons and after an appropriate incubation time, the fluids can be treated with the chemical and the changes to the biofilms and planktonic microbial populations, corrosion/pitting rates, and corrosion products between the untreated and treated experiments can be monitored. Comparing the differences between these parameters of the treated and untreated experiments can help reveal the effectiveness of the mitigation.

Case Study

Laboratory tests were conducted on a water sample collected from an asset with documented corrosion issues to determine the corrosion mechanism and to evaluate the effectiveness of biocide treatment. Carbon steel coupons were exposed for four weeks to three conditions: 1) untreated water, 2) water with 100 ppm of biocide, and 3) water with 1,000 ppm of biocide. The changes to the biofilms and planktonic microbial populations, corrosion/pitting rates, corrosion morphology, and corrosion products were monitored throughout the four weeks of testing for these three conditions.

Black surface deposits formed of iron sulfide (FeS) were observed on coupons exposed to untreated water and water treated with 100 ppm of biocide. Biocide treatment reduced the biofilm activity in both treated samples but no significant difference in biofilm microbial abundance was noticed by the end of four weeks. However, biofilms from the untreated reactor indicated the presence of several metabolic groups of microorganisms implicated in MIC (such as fermenters, methanogens, iron oxidizers, iron reducers, and denitrifying bacteria) while the treated reactors did not indicate the presence of these metabolic groups. Coupons exposed to untreated and 100 ppm biocide-treated waters showed corrosion rates up to four times higher than the coupons in 1,000 ppm biocide-treated water, indicating a correlation between the presence of the black deposits and the observed corrosion rates. However, severe pitting corrosion observed in the 1,000 ppm biocide-treated water highlighted the possibility of pit initiation and growth when the protective biocide film on the coupon surface became degraded. Characteristics of microscopic biotic pit initiation as well as signs of severe abiotic corrosion were observed on coupons from all reactors.

Integrating all the evidence collected during these tests, the probable cause for corrosion in the untreated and treated water was most likely abiotic corrosion with a minor component of MIC. The biocide treatment at 1,000 ppm concentration at first formed a semi-protective film on the coupon surfaces that perhaps helped initially in reducing corrosion rates and microbial activity and abundance, but then may have promoted severe pitting at places where the protective film was compromised as the residual biocide declined with time. In this case, biocide application did not eliminate corrosion altogether because the water sample also indicated evidence of abiotic corrosion due to high sulfides and trace amounts of oxygen. The film-forming biocide may have resulted in more localized corrosion damage at places where the protective film was broken down over time and therefore, treatment chemicals with alternative modes of action could be considered to mitigate corrosion in this environment. For more details on this case study, please refer to our CORROSION 2021 paper.[12]

Summary

MIC control includes assessment of the MIC threat, selecting effective MIC mitigation, and monitoring of MIC mitigation effectiveness. A laboratory test framework for MIC control that considers multiple lines of evidence was described using a case study. The changes to the biofilm and planktonic microbial abundance, activity, and diversity; corrosion/pitting rates; and corrosion products were monitored before, during, and after the testing. Comparison and integration of information collected about these parameters revealed the cause of corrosion, guided the selection of an appropriate mitigation method, and measured the effectiveness of the mitigation applied under the test conditions.

References

1 B.J. Little, J.S. Lee, "Microbiologically Influenced Corrosion: An Update," *Intl. Materials Reviews* 59, 7 (2014): p. 384.

2 F. Teng, Y.T. Guan, W.P. Zhu, "Effect of Biofilm on Cast Iron Pipe Corrosion in Drinking Water Distribution System: Corrosion Scales Characterization and Microbial Community Structure Investigation," *Corros. Sci.* 50, 10 (2008): p. 2,816.

3 J. Starosvetsky, D. Starosvetsky, R. Armon, "Identification of Microbiologically Influenced Corrosion (MIC) in Industrial Equipment Failures," *Engineering Failure Analysis* 14, 8 (2007): p. 1,500.

4 G.A. Jacobson, "Corrosion at Prudhoe Bay: A Lesson on the Line," *MP* 46, 8 (2007).

5 S. Campbell, S. Maxwell, "Monitoring the Mitigation of MIC Risk in Pipelines," CORROSION 2006, paper no. 06662 (Houston, TX: NACE International, 2006).

6 V. Keasler, et al., "Expanding the Microbial Monitoring Toolkit: Evaluation of Traditional and Molecular Monitoring Methods," *Intl. Biodeterioration & Biodegradation* 81 (2013): p. 51.

7 NACE TM0194-2014, "Standard Test Method, Field Monitoring of Bacterial Growth in Oil and Gas Systems" (Houston, TX, NACE International, 2014).

8 S.P. Kotu, R.B. Eckert, "A Framework for Conducting Analysis of Microbiologically Influenced Corrosion Failures," *Inspectioneering J.* 25, 4 (2019): p. 2.

9 J.B. Wrangham, E.J. Summer, "Planktonic Microbial Population Profiles Do Not Accurately Represent Same Location Sessile Population Profiles," CORROSION 2013, paper no. 2780 (Houston, TX: NACE, 2013).

10 M. Jensen, et al., "Improved Dynamic Biocide Testing Using Methanogenic and Sulfate-Reducing Biofilms Under Pipeline Conditions," CORROSION 2012, paper no. 1279 (Houston, TX: NACE, 2012).

11 L.H. Hansen, et al., "The Application of Bioassays for Evaluating In-Situ Biocide Efficiency in Offshore Oil Production in the North Sea," SPE International Symposium on Oilfield Chemistry 2009, paper no. 121656 (Woodlands, TX: SPE, 2009).

12 S.P. Kotu, et al., "Laboratory Investigation of Biocide Treated Waters to Inhibit Biofilm Growth and Reduce the Potential for MIC," CORROSION 2021, paper no. 16209 (Houston, TX: AMPP, 2021).

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