The Occurrence of Microbiologically Influenced Corrosion and Its Effects on Steel Water Well Casing

BACKGROUND

The deterioration of metallic materials by the activities of various microorganisms (microbes), hereinafter referred to as microbiologically influenced corrosion (MIC), is a ubiquitous problem that occurs in freshwater, brackish water, and seawater environments. MIC can have a wide range of short-term to long-term, deleterious effects on water wells; these include, but are not limited to, dramatically reducing the useful life of water well casing and screen, and causing a marked increase in the cost to operate a well due to its effects (e.g., lowered specific capacity, reduced well efficiency, and higher power consumption). MIC can result in pitting, crevice corrosion, selective dealloying, stress corrosion cracking, and under-deposit corrosion.

MIC is an interesting and complex topic that has been the subject of many studies regarding its occurrence, treatment, and effects. Much useful information is available on MIC in a wide variety of professional publications, texts, and on the Internet. This memorandum is intended to provide a brief, concise overview of MIC. Those readers who require a detailed explanation of MIC are encouraged to seek out pertinent information from any of the references listed herein and others.

MECHANISM

MIC occurs as microbes grow and metabolize in either aerobic or anaerobic conditions. Microbes that rely upon oxygen are referred to as aerobic; those that can live in environments with little or no oxygen are anaerobic. Table 1 presents a brief list of some microbes that are associated with MIC. As microbes go about their existence, they regularly produce gelatinous slimes, metabolites (e.g., organic acids, sulfates and sulfide) that lead to aggressive environments for metals, and microhabitats suitable for the proliferation of other bacteria species (e.g., sulfate-reducing bacteria). Microbes also participate in corrosive electrochemical reactions that can start or speed up electrode reaction.

MIC affects metallic surfaces in a unique manner. Whereas general corrosion affects an entire surface, MIC is localized. The microbes initiate the process with a search for a suitable place for habitation. They seek out irregularities on the surface of the well casing and/or screen where they can attach themselves. Once in residence, they begin their life-cycle activity and generate by-products such as sticky polymers which retain various organic and inorganic materials. These by-products are important to the development of rounded to irregularly shaped nodules; beneath each nodule is a pit. The nodule serves as the habitat for the microbe community. In a typical nodule found in an aerobic environment, microbes live within its exterior layer where they consume oxygen in the water. As they do so, they reduce the oxygen level within the outer layer of the nodule. This activity creates an environment that allows the underlying anaerobic bacteria to survive and thrive.

When a nodule is developed, it creates conditions that are chemically dissimilar to the surface material to which it is attached. This is the beginning of accelerated corrosion. As the microbe community continues to live and develop within the nodule, its by-products eventually lower the pH to acidic levels, which in turn increases the corrosive conditions within the underlying crevice on the metallic surface (i.e., well casing and/or screen). Interestingly, the acidic conditions actually promote the growth and development of other acid-producing bacteria whose own acid by-products further reduce the pH to even lower levels.

The continuance of the MIC mechanism eventually leads to the existence of a nodule over a mature pit. At this point, pH may be less than 4 and live bacteria may exist only in the outer layer of the nodule. In fact, the bacteria could be eliminated, yet traditional electrochemical corrosion would continue. Hence, this form of corrosion is now referred to microbiologically "influenced" corrosion.

Table 1 – Bacteria Known to Cause MIC

Genus of Species	pH	Temperature Range °C	Oxygen Requirement	Metals Affected
Desulfovibrio	4-8	10-40	Anaerobic	Iron, steel, stainless steels, aluminum, zinc, and copper alloys
Desulfotomaculum	6-8	10 – 40 (some 45 – 75)	Anaerobic	Iron and steel; stainless steels
Desulfomonas		10 – 40	Anaerobic	Iron and steel
Thiobacillus thioxidans	0.5–8	10 – 40	Aerobic	Iron and steel, copper alloys
Thiobacillus ferrooxidans	1-7	10-40	Aerobic	Iron and steel
Gallionella	7-10	20-40	Aerobic	Iron and steel
Sphaerotilus	7-10	20-40	Aerobic	Iron and steel

Modified from D.A. Jones, 1995.

CASE STUDY

The following case study presents a brief synopsis of one of the more serious and large-scale wellfield problems related to MIC. This narrative underscores the degree to which the integrity of steel well screen can be impacted by MIC; it demonstrates that when taken to its extreme, MIC can result in catastrophic failures.

Beginning in the late 1980's, a major, regional water supply development project was undertaken in North Africa that included the construction of a large-scale wellfield. Over a period of about 1½ years approximately 125 water wells were constructed with Stainless Steel Type 304, continuous wire-wrapped well screen that was installed within various depth intervals to extract ground water from select aquifers. Each well was gravel packed and then developed to consolidate the gravel envelope and remove the residual drilling remnants (i.e., fluids and particulates). After each well was fully developed, it was pump tested, and a permanent pump was sized to meet the well-specific pumping capacity and hydraulic conditions.

During the next phase of the project, permanent pumps were installed in the wells. At that point, some wells had been idle for up to 2 years since they were drilled and constructed. When production pumping was started, several of the wells began to pump appreciable quantities of sand and gravel. Others initially pumped highly colored water (i.e., brownish red) then began to pump sand and gravel. When these conditions were observed, pumping was stopped and video surveys were made. The down-hole videos showed that approximately 56% of the wells had confirmed ruptures and another 18% were suspected to have ruptures. These findings were followed by detailed investigations that were exhaustive and comprehensive.

The finding of such a large number of screen failures set in motion numerous studies to determine the root cause(s) of these problems. The scope of the failures analyses included, but were not limited to, materials testing, water quality testing, and structural analyses of the wire-wrapped well screen. In the end, after several years of study, it was finally concluded that the failures were directly linked to aggressive water quality and the effects of iron oxidizing bacteria. The studies found clear evidence of active corrosion that was confirmed with a scanning electron microscope and x-ray analyses. In addition, MIC was clearly observed in the down-hole videos on the screen rod welds where the failures occurred.

Following the detailed studies briefly described above, one of the conclusions was that Stainless Steel 316L would have been a more appropriate material for the water quality conditions within the wellfield. This conclusion and others were later included in follow-up well replacements.

SUMMARY

MIC has the potential to seriously impact the efficiency and structural integrity of water wells. Therefore, it is imperative that one correctly diagnose and treat such problems as soon as possible so as to interrupt and curtail the development process of the microbe community. There are many diagnostic and treatment methods available that can be implemented. Therefore, one must first identify the type of microbial community in the well, and then develop an appropriate course of treatment.

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