Metallurgical and Microbial Aspects of Microbiologically Influenced Corrosion (MIC)

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In the past decade, much has been written about microbial processes as they affect metals. Attention is also being focused on microbiologically influenced corrosion (MIC) and MIC testing of fire sprinkler systems since conditional testing of fire sprinkler piping is now required by the National Fire Protection Association, the 2003 International Building Code, and the 2003 International Fire Code.

MIC was a driving force that led to a series of events where residential oil tanks degraded and furnaces failed, precipitating a very large class action suit in the Northwest. A fire sprinkler system in a nursing home in Iowa categorically failed during a fire and reports indicate MIC as a cause of the degradation. These examples are two of the multitude of other tank and pipe deteriorations or failures that have occurred across the country where, when failures were evaluated, MIC was a contributing factor.

The completion of many corrosion failure analyses has provided deeper understanding of the cause of MIC. MIC deteriorates pipes, tanks or vessel surfaces by pitting or tunneling, thereby penetrating their cross-sections. The formation of slime or tuberculation nodules can cause blockages or reduce flow. Low flow or stagnant conditions make systems more susceptible to microbial growth.

MIC can degrade or cause to fail many different types of systems. The ultimate effect of MIC is the premature failure of metal components. The typical systems that are know to have failed include, but are not limited to: heat exchanger systems (closed and open), fire protection systems (dry and wet systems), building water piping systems, potable water transmission pipes, sewer systems, storage tanks, marine and dock systems, boiler tanks and piping, water heating or cooling system piping, and petroleum transmission pipes. Biological related corrosion problems most often initiate in new systems when they are first wetted. In older systems, problems occur when there is a change of water source, water quality, new materials of construction, or new operating conditions. Some of the operating conditions that are known to affect MIC include flow rate (velocity), temperature, pressure, pH, oxygen level and cleanliness of the system and water. The variation and interdependent affects of each parameter make analyses quite involved.

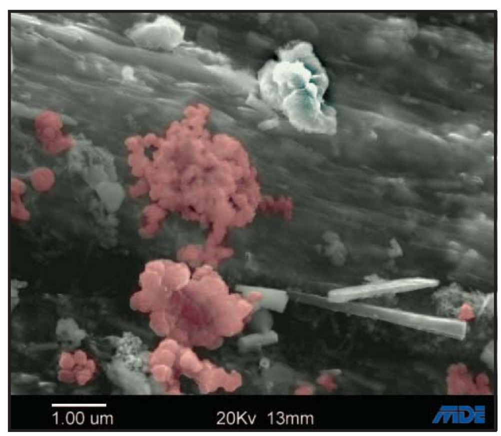
While MIC has received a large portion of recent media attention about corrosion, it is only one type of corrosion or more importantly, one influence on several modes of corrosion. To understand the causes and effects of MIC, it is necessary to understand both the metallurgical aspects of corrosion and the microbial aspects of MIC-related bacteria.

In simple terms, MIC will initiate and propagate corrosion processes in pipes, fittings, tanks, and vessels, due in part to the presence and activities of specific types of bacterial microbes. The bacteria grows, and in the process produce byproducts (waste) corrosive to metals, such as mild steel, stainless steel, copper and copper alloys, and galvanized steel. The byproducts include alkalis, acids, and reducing agents such as ammonia, hydrogen sulfides, sulfuric acid, and organic acids. The bacterial wastes also produce tubercles and biofilms which create micro-environments on metal surfaces under the tubercles. The areas under the tubercles become oxygen-depleted and support the growth of anaerobic bacteria. The anaerobic bacteria metabolize pipe wall materials and excrete acidic byproducts which chemically attack the metal component surface. The tubercles also shelter the bacteria and their growth from the water flow in the system, thus from inhibitors that may be added to protect the system, enabling the bacteria to continue growing.

In order for microbes to grow and cause microbiologically influenced corrosion, the bacteria plus four other environmental conditions must be present: metals (host location), nutrients, water, and oxygen (although certain types of bacteria need only very small amounts of oxygen). When all of these environmental conditions are present, then microbial growth will occur. When the nutrients in the system are consumed, the microbes may become dormant. When the environmental condition, i.e. nutrients, is replenished, the microbial growth resumes. Examples of this replenishment include: draining and refilling of systems, addition of water to replenish losses from leaks or maintenance, or the periodic filling of dry fire sprinkler systems.

The predominant types of bacteria found in association with MIC related corrosion:

- Sulfate-Reducing Bacteria (SRB) – bacteria that converts sulfate ions to sulfides (including hydrogen sulfide). These bacteria can grow in low oxygen environments. SRB require sufficient organic nutrients.
- Iron-Related Bacteria (IRB) – bacteria that converts soluble iron ions (ferrous) to insoluble iron ions (ferric). The ferric iron is deposited on the piping or system surfaces, creating deposits that are host sites where other bacteria can grow. These can be present in a wide variety of environmental conditions as they may be aerobic or anaerobic.
- Low Nutrient Bacteria (LNB) – microbes/ bacteria that grow in environments, such as potable water, with very low concentrations of nutrients. LNB growth will form slimes and deposits which creates host sites where other MIC bacteria can grow.
- Anaerobic Bacteria – bacteria that grow in the absence of abundant free oxygen. These bacteria can grow in environments with as little as 50 parts per billion (ppb) dissolved oxygen.
- Aerobic Bacteria – bacteria that grow in the presence of free oxygen.



E-SEM Photomicrograph showing likely SRB cocci

It is also important to understand the basic stoichiometric equations of corrosion and the associated electrochemical reactions to comprehend the resultant degradation in the different types of metals that may be affected. All corrosion processes, including MIC, are electrochemical processes. Corrosion is a transference of positive and negative ions to change oxidation states which causes a removal of structural or base material and the

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formation of a compound either helpful or hurtful to the system. It can be autocatalytic (growing without external help) or system-dependent (needing to be "fed" with nutrients).

Some types of microbial reactions create ammonia. Fittings and piping systems are designed to operate at stress levels below that of the yield strength for the composition alloy. However when some copper or brass alloys are used in the presence of ammonia, the ammonia sensitizes the metal so that residual and/or service stress levels are exceeded and intergranular stress corrosion cracking occurs. Ammonia attacks at the grain boundaries, sensitizing them and allowing slow crack growth.

Copper, stainless steel, aluminum and some other less commonly used alloy surfaces rely on passive films or specific elemental atomic layers to combat degradation and corrosion. MIC associated bacteria and their chemical byproducts are very destructive to some alloys. Sometimes the microbes associated with MIC may come and go without detection but leave surface characteristics that disrupt the passive layer on these alloys. Brasses, bronzes, and copper systems, such as piping, fittings and heat exchanger systems are more susceptible than other alloys in this group.

Copper-Base Alloys: These alloys are most susceptible to MIC because they are soft and can incur impingement that can cause erosion and other wear problems if their passive layer is interrupted. Newly installed products of these alloys typically do not build up their protective layer for a period of time. If MIC-related bacteria are present, or there are elements like chlorides or sulfides in the initial solutions contacting the metal, the passive or protective layers form other complex chemical compounds rather than copper oxide. The problem with these complex chemical compounds are their strength; they are typically much weaker than copper oxide and break down at lower flow rates allowing a variety of mechanisms to attack or degrade the substrate. If systems with copper-based systems coated with these poor passive films (the complex chemical compounds) are cleaned off, further attack is inevitable, through a reiterative process.

Stainless Steel and Aluminum: These alloys have tough substrates and they develop tough passive layers. Aluminum is not as strong as stainless steel, but it is still much stronger than most bronzes. Although each of these alloys is durable in the applications where oxygen is plentiful, they are not sturdy when in an oxygen-starved environment. These alloys are not robust when around anaerobic, aerobic or other types of bacteria as the passive layer is easily penetrated by them. Thus, in the presence of MIC-related bacteria, systems constructed of these alloys are susceptible to MIC and MIC related intergranular stress corrosion cracking. The most common point of susceptibility is welded areas and highly stressed areas that exceed the threshold stress level for the intergranular stress corrosion cracking.

Steel: This material develops less dense passive layers than other materials. It is penetrated immediately by microbes present unless there is some sort of insulating (barrier) aid such as a coating, conversion chemical, calcium carbonate in water, or cathodic protection. MIC is found in these iron-base alloys more often than any other alloy system.

MIC-related bacterial growth typically occurs in systems within specific temperature ranges, depending on the type of bacteria; an "ideal" range is often reported as 4° to 49°C. Bacterial growth typically hibernates below 4°C. Some types of bacteria favor other temperature ranges; for example, most common strains of SRB grow best at 25° to 35°C. A few thermophillic types of SRB grow more efficiently at more than 60°C, and one type is capable of growing at more than 100°C. While MIC more favorably grows in their typical temperature ranges, growth in other temperature ranges should not be discounted. MIC has been found in extremely cold environments such as freezers or piping systems of Alaskan villages north of the Arctic Circle.

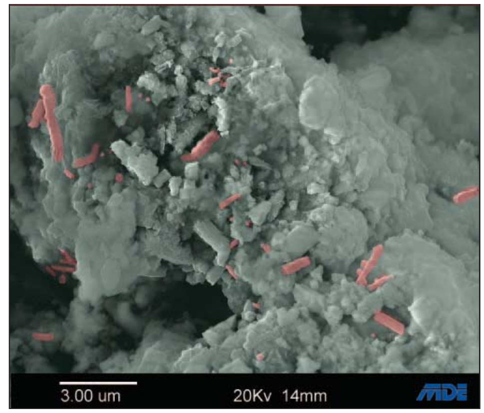
If microbiologically influenced corrosion is suspected due to observation of slime, restrictions in flow, or leaks/pinhole leaks in pipes, the testing for the presence of MIC is warranted to determine:

- Whether bacteria related to MIC are present and, if so, their relative concentration
- The extent of the corrosion present
- The source of the corrosion
- Limits of the MIC affected system components

Comprehensive testing is performed by collecting a number of samples at various locations in a system and sampling the make-up water. Depending on the system configuration, visual observations, and problems experienced at the facility, sampling during one or more time intervals may also be appropriate. The samples should be cultured on media for the presence (and relative concentration) of low nutrient bacteria, sulfate-reducing bacteria, iron-related bacteria, and aerobic bacteria. Timely culturing of the samples is very important as MIC-related bacteria become dormant when the environmental conditions are altered. Scaling or other chemical conditions in the water affect system corrosion and the interpretation of MIC sampling results; therefore, chemical testing of each sampling location and sampling interval is also useful. The results of the water chemistry testing can also be beneficial in ascertaining how far along the corrosion is, due to MIC-related bacteria.

Where leaks are present, appropriate sampling may also include metallurgical analysis of system components. The metallurgical engineer analyzes the component using electron microscopes to ascertain the nature of all corrosion and failures present.

Microbiologically influenced corrosion, like other corrosion, causes degradation, deterioration and failures. Understanding the causes, effects, and appropriate investigational methods is the first step in addressing MIC related problems.



E-SEM Photomicrograph showing likely IRB rods at MIC corrosion site

Cross-section of galvanized pipe showing MIC effects. Note: pitting has reduced wall thickness by 60%.

MDE Inc is a multi-discipline forensic engineering and laboratories consulting services firm providing MIC testing and consultation, as well as forensic, investigational, and reconstruction engineering and industrial hygiene services nationwide.