MICROBIOLOGICALLY INFLUENCED CORROSION IN FIRE SPRINKLER SYSTEMS

By Bruce H. Clarke

INTRODUCTION

Numerous reports in the past decade have described the rapid development of pinhole-sized leaks and highly obstructive interior growth developments in sprinkler system piping, fittings, and supply tanks. Some occurrences have been reported after less than one year of system service.[1] In many of these cases, the cause has been found to be microbiologically influenced corrosion (MIC).

MIC in fire sprinkler systems has grown from an obscure topic of regional discussions in the early 1990s to one now generating widespread concern, speculation, and debate throughout several countries. Unfortunately the building owner, fire protection engineer, and contractor faced with addressing this problem still have relatively few universally accepted practices within our industry to reference. In fact, many calls for help are still answered with theoretical treatment solutions and, in some cases, inaccuracies. And while most fire protection professionals have now heard of this problem, proper diagnosis and treatment are still not fully understood.

MIC DEFINED

Corrosion occurs in many forms and can be defined from many scientific viewpoints. Microbiologically influenced corrosion is one type. For the fire protection discipline, it can specifically be defined as:

An electrochemical corrosion process that is concentrated and accelerated by the activity of specific bacteria within a fire sprinkler system, which results in the premature failure of metallic system components.

This definition fully captures both cause and effect. But a more detailed review is required to fully clarify the true nature of MIC and the complexities in addressing this problem.

Electrochemical Corrosion Process

Metallic materials can degrade and fail from various causes including corrosion. In general, corrosion can be defined as the "wearing away of material." As in other forms of corrosion, with MIC the "wearing away" or removal of material occurs through a series of *electrochemical* interactions. Thus both an "electrical" and a "chemical" component are required for MIC. The electrical component occurs through electron transfer.[2] This is basically the removal of pipe wall material one electron at a time. Electrons are stripped away from pipe material atoms through various forms of oxidation which are dependent on the bacteria involved. The chemical component is the result of the bacterial metabolic process that occurs. This creates various organic and mineral acids which chemically decompose metallic surfaces from direct contact.[3] The section on THE MIC PROCESS will describe this in more detail.

Concentrated and Accelerated

The MIC process is both *concentrated* and *accelerated* in comparison to typical corrosion seen in sprinkler systems. All metallic systems normally begin to corrode from the instant moisture meets metal. This is called general or uniform corrosion.

With general corrosion, a thin layer of oxidation occurs relatively evenly throughout the entire pipe wall surface. This type of corrosion is typically not treated nor a significant concern in fire sprinkler systems. This is because it does not significantly change a pipe's interior surface roughness (i.e., "C-factor"), and the rate of decay is naturally self-limiting. A typical corrosion rate in sprinkler pipe is highly dependent on water quality but is usually negligible at under 1.0 mil/year. With MIC, this relatively slow corrosion rate is abnormally accelerated up to 10 mils/year. Put in perspective, schedule 40 pipe has a wall thickness of approximately 20 mils.

When microbiologically influenced corrosion occurs, general corrosion also becomes concentrated, or localized, into high-activity pockets or cells. This causes pitting, which can drastically change a previously smooth interior pipe wall surface and its associated "C-factor."

Activity of Specific Bacteria

As defined, MIC is from the activity of *specific* bacteria. Various bacteria are present in all ecosystems. Sprinkler systems also normally have many kinds, but only a relatively small number have the potential to cause rapid system destruction. Only a few *specific* bacteria *concentrate* and *accelerate* the general corrosion process. Thus a high "general" bacteria count is meaningless. It is important to understand that the bacteria associated with MIC do not produce a new corrosion process but, as stated, simply concentrate and accelerate general corrosion which is already occuring.[3] Microbiology influences, not induces, corrosion.

How are these "specific" bacteria defined? MIC-related bacteria are primarily classified by oxygen tolerance: being *aerobic* or *anaerobic*. *Aerobic* bacteria require oxygen to flourish and reproduce. *Anaerobic* bacteria are those that do not require oxygen to flourish and reproduce.[1] And, while most species only flourish with one atmosphere and find the other toxic, facultative bacteria can survive in both aerobic and anaerobic environments. All three types play a role in the relatively complex and random interactions that can occur in microbiologically influenced corrosion.[4]

In defining bacteria further, classification is not absolute and can become relatively confusing. The most commonly used method of categorizing bacteria associated with MIC further is by metabolism. These labels are basically definitions of what each bacteria type eats (or metabolizes) and excretes as a byproduct. As these terms imply, where plants use photosynthesis (i.e., light) to develop energy, bacteria use chemosynthesis (i.e., eating/breathing various chemicals or minerals).

However, use of these metabolic tags are not universally replicated and can be somewhat confusing. A single bacteria type may fall under more than one metabolic definition. Some of the commonly referenced categories include Sulfur-Reducing Bacteria, Metal-Reducing Bacteria, Acid-Producing Bacteria, Iron-Depositing Bacteria, Low-Nutrient Bacteria, Iron-Related Bacteria, Iron-Reducing Bacteria, Iron-Oxidizing Bacteria, Sulfate-Oxidizing Bacteria, Slime-Forming Bacteria, Sulfate-Reducing Bacteria, and Iron Bacteria.[1,3,4]

Finally, all bacteria can be classified by their scientific name under phylum, class, order, family, genus, or species.[5] For example, one type of sulfate-reducing bacteria is anaerobic and metabolizes sulphate to sulphide. The sulfate-reducing bacteria group includes the genera desulfovibrio, desulfobacter, and desulformaculum.[3] All are of the phylum Thiopneutes, which interestingly translates from Greek to "sulfur-breathers."

Within a Fire Sprinkler System

The specific source of MIC is consciously omitted from the captioned definition. Bacteria is only indicated to be *within the fire sprinkler system*. Typically, a sprinkler system's water supply is incorrectly considered to be the only source for bacteria. Although there currently are no conclusive relational studies in the fire protection industry, there are growing beliefs this is not the only source of bacterial infection. Besides all water sources, bacteria capable of causing MIC are potentially present in all soil, air, and cutting oils. Thus the manufacture, shipping, storage, and flushing of system materials should be addressed in all MIC investigations.

Obstructive growth from MIC.

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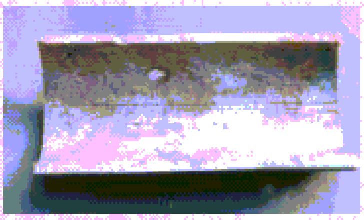
MIC does not only occur in water-filled systems. Dry pipe systems are also susceptible.[1] In fact, evidence shows that dry systems may be more susceptible to damage than fully wet systems due to the humidified atmosphere that is created after a first trip test. This could create the right atmospheric moisture content for some bacterial types to thrive.



Above Top: Interior pitting and roughness created by MIC.
Bottom: Exterior pinhole.

Premature Failure

The ultimate effect of MIC is the *premature failure* of metallic components. This failure can take two forms. First is the failure of a system to hold water (i.e., leakage requiring component replacement). This is most often seen in the development of the pinhole-sized leaks often referenced as a primary MIC infection indicator. This is also typically the only concern in many treatment investigations.

Second, and more concerning, is the failure of a system to achieve its designed purpose: that of fire control. Several systems with MIC have been found with sprinkler drops completely plugged with the debris generated as a byproduct of the MIC process (called biofilm or biosludge). Sprinkler system feed mains have also been found with up to 60% obstruction from biological growth.[6] This could present an obvious hydraulic concern as many sprinkler systems today will not provide fire control with just a 15%-20% flow reduction due to design.

What is considered *premature?* With regard to system function, at any time a system is "in service" and fails to operate as designed, it has experienced "premature failure." If a system is operational and properly maintained, it is *always* expected to work as intended. This is the foundation for the public's trust we build upon in selling the value of sprinklers. Unfortunately, like the recent Omega sprinkler which was recalled after it did not perform as expected in *every* instance, the effects of MIC could conceivably be the next large public relations problem our industry will have to address.

What constitutes premature with regard to the integrity of specific system components must also be discussed. Long-term warranties are not typical with system components, but with proper maintenance, a sprinkler system is typically expected to last for a minimum of 30-60 years before major repairs are required.

Metallic System Components

The word *components* and not simply "pipe" is used as the captioned point-of-failure. While pipe is the typically seen failure point, there are increasing reports that sprinkler orifice caps, control valves, fittings, and supply tanks are also being damaged. Only *metallic* components are susceptible to MIC, while plastic materials are not directly susceptible.

Plastic components are, however, subject to bacterial debris blockage from upstream bacterial activity in metallic components. The term *metallic* is also chosen over steel. With the exception of a possibly very select few steel alloys, virtually *all* metallic materials currently in use today are susceptible to biological corrosion.

Above: Interior biofilm buildup with clearly seen corrosion cell tubercle shell.

Left: Interior biofilm growth and exterior pinhole leak – at approximate two o'clock point on pipe wall.

THE MIC PROCESS

The corrosion process can be very complex with many variable interactions at a cellular level between aerobic, anaerobic, and facultative bacteria. However, several steps in the process are somewhat universal: [1 1 1 4]

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1. Bacteria enter the system, attach to metallic components, and begin to rapidly colonize and reproduce.
2. Aerobic colonies metabolize nutrients from the water and/or the metal surfaces they are attached to, and subsequently excrete a polymer film byproduct that bonds together to form crustaceous nodules called tubercles.
3. Tubercles and associated biofilms create microenvironments on the metallic material surface (under the tubercles).
4. The underdeposit area (i.e., under the tubercles) becomes oxygen-depleted (i.e., anaerobic and anodic) in relation to the surrounding system water or air (which remains aerobic and cathodic).
5. Underdeposit anaerobic bacteria metabolize pipe wall materials and excrete an acidic byproduct. Relative acidity and alkalinity levels within the tubercle shells are reduced to an approximate 2-4 pH, which chemically attacks the metallic component surface.

The described corrosion process can continue indefinitely until the aerobic and anaerobic bacteria in the system are killed. The tubercles created from colonization must also be broken down to destroy the underdeposit microenvironment. This is because even without bacteria in the underdeposit of a corrosion cell, the process can still continue indefinitely as the corrosion chain in its final phases is no longer reliant on their activity.

CURRENT TREATMENT REFERENCES

Currently, the fire protection industry has a very limited amount of usable references supported by scientific data. However, several allied groups can provide excellent information on data from other industries.

The National Association of Corrosion Engineers (NACE) has many published studies and overviews about MIC detection and treatment. The American Society for Testing and Materials (ASTM) offers several publications on proper bacterial testing practices.

The American Water Works Association offers standards describing the proper management of the somewhat hazardous chemicals typically used in injection devices attached to sprinkler systems for microbial control. Depending on how a facility's water is supplied, this may be a very important reference to maintain compliance with the nationally mandated Safe Water Drinking Act. The B300 series of publications specifically address disaffection chemicals (such as hypochlorites commonly used in treatment), and the B500 series of documents specifically addresses scale and corrosion control chemicals (such as the phosphates commonly used in treatment).

The National Fire Protection Association (NFPA) fire codes also address MIC. But these references are still very limited. The most impacting to our industry thus far was a section added to the 1999 edition of *NFPA 13: Standard for the Installation of Sprinkler Systems*. Section 9-1.5 covering water supply treatment states:

In areas with water supplies known to have contributed to microbiologically influenced corrosion (MIC) of sprinkler system piping, water supplies shall be tested and appropriately treated prior to filling or testing of metallic piping systems.

While this has generated a flood of needed curiosity, it does little to address the resulting questions about proper treatment. First, there is no explanation as to what is considered an area *"known to have contributed to microbiologically influenced corrosion."* Data indicates data thus far on confirmed cases have been widely inconsistent, varying within city blocks and even within building complexes fed off common loops. If one case is found in a given municipal area, is the entire community served by the same water supply now considered a *"biological activity area?"*

It also requires that building owners be fully familiar with the sources of their fire protection water. This can be very difficult as many municipalities switch between and blend multiple sources such as canals, various wells, rivers, lakes, and reservoirs. It also does not address the fact that contamination can come from sources other than the water supply, as already discussed.

Finally, this section indicates that sprinkler systems *"shall be tested and appropriately treated prior to filling."* The "who," "how," and "when" are still in debate by those addressing this issue. *Who* is truly qualified to make the determination of *when* a failure is the result of MIC and if a biocidal treatment program will prevent all future failures? And *how* is a system best tested (i.e., most accurately and cost-effectively) to confirm MIC? Almost anything requiring laboratory work can be overtested... at a price. These are questions where answers are still evolving.

National Fire Code 25: Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems, 1998 Edition, Section 10 and Appendix 10 discuss MIC treatment and detection in some detail. *NFPA 25* also provides other inspection requirements that can be useful. These include:

Section 7-3.4.1 stating *"...system piping and fittings shall be inspected quarterly for external conditions (e.g., missing or damaged paint or coatings, rust, and corrosion."*

Section 7-3.6 stating *"...the dependability of the water supply shall be ensured by regular inspection and maintenance, whether furnished by a municipal source, on-site storage tanks, a fire pump, or private underground piping systems."*

TREATMENT

The analysis required to properly select a course of action to address MIC is typically outside of the scope of work that most sprinkler contractors and engineers are competent to directly provide. Thus, until treatment methods become universally proven and standardized, the most critical step in proper mitigation begins with the selection of a qualified corrosion control consultant.

With the wrong choice, a building owner could spend a large amount of

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money on a problem that will likely recur. And a poor treatment choice could actually accelerate the corrosion rate and affected area beyond that experienced before treatment.

The company chosen to determine treatment must have a detailed knowledge not only of microbial corrosion control but also of metallurgy and sprinkler system dynamics. Fire sprinkler systems have flow characteristics and concerns that are much different from most common industrial process systems where MIC is typically addressed.

Most other industries deal with MIC in systems containing fluids that are either always static or always flowing. And unlike sprinkler systems, dynamic systems have flow rates that are relatively constant, making prescribed chemical dose rates constant. A constant flow rate does not occur in sprinkler systems. Variable differences are seen with system drains and refills, inspectors testing, and main drain tests. The dose rate for each of these flows must be considered to ensure the chemical injection rate is always effective. Most other industrial systems also have multiple points where biocidal chemicals can be injected. Sprinkler system water can realistically only be treated at system risers, back flow apparatus, or suction tanks.

Finally, as previously stated, it is critical to understand that premature system failure can be a function of both bacterial infection and a water quality that is incompatible with components. In fact, in the majority of premature system failure cases, water chemistry is likely to also be a major factor. A high bacterial count does not always indicate MIC will occur, and conversely, a low bacterial count does not discount that MIC has occurred in the past in a given system and will not occur in the near future.

Analysis

In systems suspected of already being infected, the first step is to have all possible water supply sources (tank, city mains, ponds, rivers, etc.) and the interior of each system tested for bacterial levels and activity. While this detection is not difficult with current technology, analysis of these results is somewhat complex. And, as previously stated, in determining treatment, bacterial detection is worthless without factoring in water quality.

The laboratory used for analysis should be capable of giving conclusive details of water supply mineral and chemical levels, pipe wall deposit compositions, and type-specific bacterial counts. Multiple tests are used in these analyses from simple bacterial incubation with visual inspection to sulfur print or DNA testing. Obviously, not all tests are required nor are necessarily needed. Current preferred analysis methods run the spectrum, depending on the consultant chosen. Costs for such testing can also vary widely.

In new systems, if MIC-causing bacteria *could* be present, all sources should be tested. It is critical that susceptibility be determined *before* any systems are filled or tested in any way. This is because if water tests are positive, a chemical injection system must be installed and used immediately after completion – including in hydrostatic testing and preliminary fills.

Once a system is filled with infected water, treatment can become exponentially more complex as any future treatment from a chemical injection system must now be effective in remote and stagnate system legs. In bacteria-positive areas, several additional water quality tests should be completed throughout the first year of service to ensure contamination has not occurred from any other sources.

Mitigation in Affected Systems

When MIC is confirmed in operational systems, the building owner is first faced with a fundamental question. Can the system be salvaged (i.e., cleaned) or does it have to be replaced? Currently, this decision is not supported by documented best practices in our industry.

Who is qualified to determine if a system can be cleaned or must be replaced? Pipe cleaning is typically an option when corrosion (i.e., pitting) is not excessive. However, *excessive* is a relative term. To answer this question, the resulting after-cleaning quality of the pipe must be considered – both for future longevity and system hydraulics. The resulting frictional loss from numerous pits after cleaning could affect system performance. This, of course, is typically outside of the scope-of-work of most corrosion control consultants. Who is actually qualified is currently interpreted in many ways. When replacement materials are chosen that are different than those of the original system, this also must be accounted for in hydraulics analysis of the post-treated system.

Chemical Injection

Once system components have been cleaned or replaced and sterilized, a chemical injection system must be installed to prevent recurrence. Once installed, this system will be required to be operational continuously. As with any other mechanical system, this will require continuous system preventive maintenance.

When such a system is chosen, the applicable AHJ should be consulted. In addition to frictional loss concerns mentioned from changes in pipe surface roughness, increased back flow prevention hardware may be required. This could mean a 10 psi (0.7 bar) or more pressure drop to sprinkler systems in addition to that created by pitting if cleaning is chosen. In new system design, added alarm system contacts must also be planned to monitor injection system chemical levels, operational status, and trouble signals. Many pre-engineered systems available today have readily available contact points for these signals. As with detection, the perceived "best choice" depends on the person choosing and is highly variable.

Several commercially available chemical injection systems have been specifically designed for installation on fire protection systems. Some simply use existing hardware and chemicals modified from MIC treatment in other utilities, such as cooling towers. None of the systems currently available are believed to be UL-listed or FM-approved specifically for use as a

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sprinkler system components. And while most appear to be effective when properly installed and maintained, reliability and effectiveness have not been time-proven when compared with most industrial system benchmarks. Past references should always be investigated with any choice.

Most injection systems currently available are designed to work with specific chemicals. These selected chemicals and dose rates are critical. Some bacteria can develop chemical resistance over time if doses are not strong enough and bacteria are not quickly killed. A small number of MIC-related bacteria (such as the genera Bacillus and Clostridium) also have the ability to convert to a spore state when they encounter adverse conditions which are not lethal.[3,4] Spores are impervious to chemical penetration and thus can then survive biocidal treatments indefinitely. And while subsequent treatments may then slow or stop their activity, they will reappear when/if treatments are stopped and resume colonization. With a weak chemical attack, bacteria may also become resistant to the chemicals chosen.

As with most other parts of the treatment system, the choice of chemical depends on the consultant. These generally include penetrants and biodispersants to break up the tubercles which protect underdeposit colonies, a biocide to kill the bacteria in the colonies, and a corrosion inhibitor to protect of the interior system surface.

Unlike most other industrial systems treated for microbiologically influenced corrosion, several chemical interactions must be considered. First, sprinkler systems are typically located directly over people. Chemicals used must therefore be nontoxic in contemplation of accidental discharge. Second, system designs typically place water discharge (such as from inspector's test ports) into foliage or biologically sensitive drains. Most municipal waste water treatment plants (to which typical drains ultimately flow) require bacterial activity to decompose waste. Too large a quantity of biocides in municipal drains could be a problem.

In conclusion, a complete toxicity review with the highest possible biocidal chemical concentration must be completed. As much as possible, these chemicals should be noncombustible, colorless, odorless, and nontoxic. These must also be nondeteriorating to rubbers and polymers such as those used on pipe couplings and sprinkler o-rings. Chemical storage should also be reviewed, as several currently used can degrade rapidly with heat and may create relatively toxic vapors.

Some of the more common chemicals currently in use specifically for microbial control in sprinkler systems include quaternary ammonium compounds, organo-sulfur compounds, bromines, carbamates, isothiazalone, phosphates, and chlorines. Sodium silicate is effectively used in bulk quantities by several municipalities as an inhibitor but this should be avoided for individual systems due to the potential sprinkler head plugging overdosing can cause.

FUTURE ACTIVITY

The National Fire Sprinkler Association formed an "MIC Task Group" in 1996 to address these associated issues. Their work continues, and they currently have the only known Internet-accessible Web site for reporting suspected MIC cases. The National Association of Corrosion Engineers (NACE) recently formed a task group specifically to investigate MIC fire sprinkler systems – a problem they have been addressing for years in other industries. And NFPA recently formed an "MIC Task Group" as an extension of the *NFPA 13* New Technology Task Group. This group is working to develop a report containing specific recommendations for the prevention and treatment of MIC. It is planned for inclusion in the next edition of *NFPA 13*.

Studies by many universities, government, and private industry groups will also continue to research microbial control in other industries as they have for the past several decades. This should continue to provide improved treatment options in our industry. Some currently being investigated include *in situ* steam sterilization and gas fumigation as possible alternatives to chemical cleaning and sterilization. Other studies are looking at using engineered bacteria to control corrosion-causing bacteria through various interactive means. And studies into the development of bacterial-resistant materials such as chemically impregnated steel or plastic-coated pipes also hold promise. This may include work with biostat coatings. These are films, paints, and coatings that do not kill organisms but simply inhibit their growth or attachment to metallic components.

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