SUPPLEMENT 3

Microbiologically Influenced Corrosion in Fire Sprinkler Systems

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Editor's Note: *Supplement 3 has been included to provide the user with background information related to microbiologically influenced corrosion or MIC. While MIC has been in existence for some time, it has recently become a maintenance problem, through recognition of the source of corrosion, for those involved in the maintenance of fire protection systems. The supplement discusses the microbial corrosion process and recognition and treatment of MIC for fire protection systems.*

Beginning in the early 1990s, concerns began to increase about microbiologically influenced corrosion (MIC) affecting fire sprinkler systems due to multiple cases involving the abnormally rapid development of pinhole-sized leaks and highly obstructive interior biological pipe growths. Most of these occurred in systems well before the end of the system's life expectancy, after 5 to 20 years of service. However, some systems began to show signs of critical obstruction and began developing leaks in less than one year. Research into the cause of these leaks, which have greatly increased in the last two decades, has led to a growing awareness of the problem. In the past 20 years MIC has grown from a relatively unknown topic of regional discussions to one now generating widespread concern throughout several countries. MIC in fire protection systems also has become the subject of a wide array of speculation, debate, and, in some cases, gross inaccuracies.

At the time this is being written, there are few time-proven solutions that are also universally accepted "best practices" in the fire protection industry. Although MIC and biological growth control have been extensively researched in many allied engineering fields for decades, treatment in fire sprinkler systems is relatively new. And although there are several detection and treatment systems that appear to be effective, long-term data to support overall effectiveness claims are still limited. This chapter will provide an overview of the issues related to microbiologically influenced corrosion in the fire protection industry.

For related topics, see the following chapters in Section 16 of the *Fire Protection Handbook* [1]: Chapter 1,

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"Principles of Automatic Sprinkler System Performance," Chapter 2, "Automatic Sprinklers," Chapter 3, "Automatic Sprinkler Systems," and Chapter 11, "Care and Maintenance of Water-Based Extinguishing Systems."

DEFINING CORROSION

General Corrosion

Generating a universal "working definition" for MIC in fire protection is complex. And to understand the relationship of MIC and sprinkler components, general corrosion and its various causes must first be understood. One edition of *Webster's* defines *corrosion* as "the wearing away of materials by chemical action(s)." Another edition simply defines it as "the wearing away of material gradually." The on-line encyclopedia *Encarta* describes corrosion as "specifically being related to the gradual action of natural agents such as air or salt water on metals." All these definitions are true generally but are also very confusing to those in the fire protection industry who are looking for answers. Even definitions presented by the corrosion engineering communities, though more detailed, can at times appear somewhat contradictory and very confusing.

Corrosion can occur from many biophysical reactions and be described from a multitude of scientific viewpoints. "General corrosion" typically refers to uniform corrosion that occurs on most unprotected metallic systems. This can be associated with the uniform "rust" layer seen on many steel structures. Besides rust from oxidation, several other types of general corrosion include stray current, uniform biological, galvanic, molten salt, dealloying, chemical, high-temperature, and general carburization. And some specific nonbiological corrosion processes having adverse effects on fire protection sprinkler systems, which must always be considered with MIC, include oxygen, acid, and oxygen-acid corrosion. [2]

Microbiologically Influenced Corrosion

In contrast to general, or uniform, corrosion, MIC is a form of localized corrosion. Material is lost at discrete points instead of universally across an entire surface. There are several types of localized corrosion, including pitting, crevice, cratering, and filiform. (See Exhibit S3.1.)

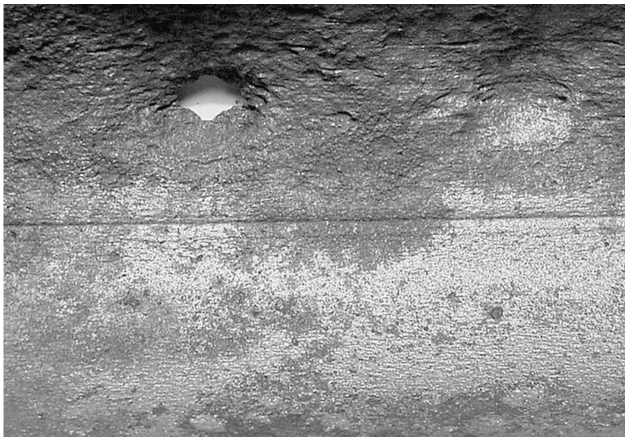

EXHIBIT S3.1 Interior Pinhole Leak.

As with the various other types of corrosion, MIC can take many forms and affect different systems in unique ways. But, for the fire protection profession, an industry-specific definition can be developed. This definition captures both the causes and effects of this problem with several continuous generalities to avoid some of the current inaccuracies. Thus, microbiologically influenced corrosion in fire protection systems can be described as "an electrochemical corrosion process that is concentrated and accelerated by the activity of specific bacteria within a fire sprinkler system resulting in the premature failure of metallic system components." [3]

THE CORROSION PROBLEM

Concentrated and Accelerated Corrosion

All metallic systems normally begin to corrode to various degrees from the instant moisture contacts metal. Typically, this appears as general corrosion. By definition, in comparison, the MIC process is both *concentrated* and *accelerated*. With general corrosion, when moisture is introduced into a system, a thin layer of oxidation occurs relatively evenly throughout the pipe wall surface. This type of corrosion is typically not a significant concern in fire sprinkler systems and does not require treatment because it does not change a pipe's interior surface roughness (i.e., C-factor) unevenly. The rate of decay is also typically slow. A typical corrosion rate in sprinkler pipe is highly dependent on water quality, but with MIC, this relatively slow corrosion rate is abnormally accelerated and not evenly dispersed. The result changes a relatively smooth pipe to one with pits and valleys.

$$p = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

where:

p = frictional resistance in psi/ft

Q = flow in gpm

C = frictional loss coefficient

d = internal diameter of pipe

While there has not been a detailed study on exactly what amount of pipe change (or changes in pipe wall roughness) is unacceptable, the Hazen-Williams formula makes several points clear:

1. Pipe surface texture is critical in sprinkler system effectiveness. With "C" based on pipe wall smoothness, any increase in roughness decreases the value of "C" and thereby increases the pressure loss in each foot of sprinkler pipe. Even a small amount of internal corrosion, especially in main feed areas, could potentially make a system ineffective in fire control.
2. Pipe diameter is a significant contributor to friction loss. Thus, the smaller the pipe, the more dramatically corrosion affects friction loss and overall performance.

While this formula is not intended to be used for nonuniform pipe surfaces, it is clear that random pockets of biological growth have the potential to affect performance. This is especially true if a sprinkler system has a minimum design buffer, which is regularly the case. (See Exhibit S3.2 and Exhibit S3.3.)

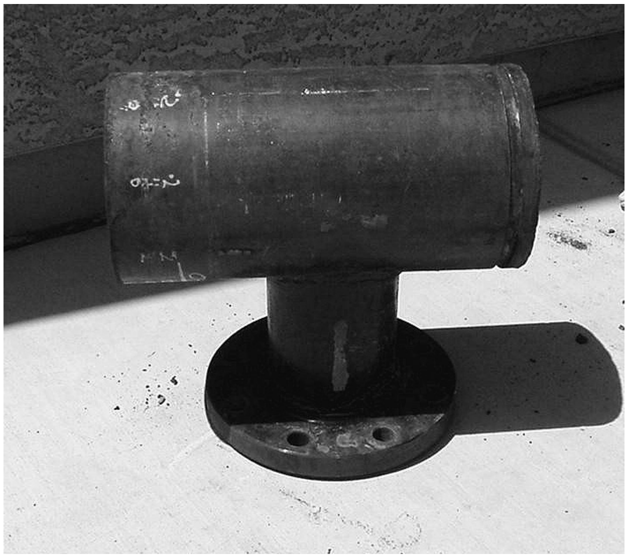

***EXHIBIT S3.2** Exterior View of Pipe with No Signs of Internal Corrosion.*

MIC is the result of specific bacteria (see section on defining MIC). A multitude of bacteria are always omnipresent in all ecosystems, including the interior of sprinkler systems. Just as only a small number of bacteria on earth have the potential to cause human sickness, only a relatively small number of bacteria have the potential to cause the rapid system destruction currently linked to MIC. Thus, as defined, only a few specific bacteria concentrate and accelerate the general or uniform corrosion process.

***EXHIBIT S3.3** Interior View of Pipe Shown in Exhibit S3.2 with Approximate 65 percent Obstruction to 6 in. Tee Connection.*

Premature Failure

The ultimate effect of MIC in fire protection systems is the premature failure of metallic components.

Premature Failure Defined. It is clear that MIC and other related forms of corrosion cause sprinkler systems to fail prematurely. What constitutes "premature" with regard to the integrity of specific system components has not officially been defined in the industry. Long-term warranties are not typical with system components; however, with proper maintenance a sprinkler system is typically expected by the industry to last over 50 years before major repairs are required. In most cases of MIC, it has appeared that after treatment of the affected areas, healthy systems can be expected to exceed this normal life expectancy.

However, as discussed, failure is a function of both integrity and function. And a system without leaks is never considered acceptable if it fails functionally (i.e., in fire control). Any time a system is in service and fails to operate as designed, it has experienced an unacceptable premature failure.

Forms of Premature Failure. Premature failure can take two forms, both requiring individual consideration. First is the failure of a system to hold water — in other words, the presence of pinhole leaks that require component replacement (see Exhibit S3.4). Leaks can cause significant damage and require immediate action. Leaks can also lead to excessive direct and indirect costs, as well as inherent risks from repeated system impairments.

In one known case, MIC-related leaks resulted in the shutdown of an aerospace manufacturer's global computing center. [4] A pinhole leak developed in a wet pipe

EXHIBIT S3.4 Exterior Pinhole.

sprinkler branch line located over the mainframe equipment of the computing center. Water from the leak not only damaged computing equipment but also resulted in over 5000 hours of lost operations time. Property damage from similar leaks at other sites has also been documented in the millions of dollars. [4,5]

The second and more worrisome effect is the failure of a system to operate as designed to achieve fire control. This failure not only affects property loss but also could threaten lives. Several systems with MIC have been found with obstructed sprinkler drops, the result of debris generated as a by-product of microbial activity (called biofilm or biosludge). Many in the industry have found systems with feed mains over 60 percent obstructed from biological growth. [5,6] An analysis of corrosion buildup indicates that thousands of pounds of debris can accumulate in medium-sized piping. [7] This buildup of debris presents an obvious hydraulic concern, as many affected sprinkler systems today will not provide fire control as the required discharge criteria, in terms of flow and pressure, are not available due to obstruction and associated frictional pressure loss.

Extent of MIC in the Sprinkler Industry

Currently only a limited number of credible national studies on the extent of the MIC problem in the fire protection industry exist. Most data are primarily anecdotal. No detailed comparative engineering-based study on effectiveness of the various treatment options currently being marketed has been completed. Complicating this lack of data, reported MIC cases rarely have secondary analysis to differentiate MIC as a primary contributing cause over other types of corrosion involving similar symptoms. Equally important, follow-up engineering data on treatment are rarely published.

The results of MIC in other industries are well documented. The Energy and Power Research Institute has estimated that corrosion in the U.S. electric power industry costs 5 to 10 billion dollars each year. Corrosion is said to be the culprit in half the forced outages each year in steam-generating plants. [8] And data collected from before the 2001 "U.S. power shortage" showed corrosion to be the primary factor in more than 10 percent of U.S. power generation costs. [8] In the gas and nuclear industries, MIC is specifically said to account for 15 to 30 percent of corrosion-related failures. [9] And, reports indicate that to prevent such problems, North American companies spend in excess of $1.5 billion per year (over $7 billion globally) on treatment chemicals to prevent microbial corrosion and fouling. Similar information, as mentioned, is not available for the fire protection industry. Although several industry groups have been attempting to compile data on this problem for several years, only two national studies have been published for the fire protection industry. [10,11] Thus, the true extent and cost of the problem are still not fully known.

In 1996, the National Fire Sprinkler Association sent out a questionnaire in its quarterly membership magazine requesting member information on sprinkler system failures that have been experienced. Results yielded approximately 40 responses from across the United States and Canada, which appeared to indicate that MIC was a "widespread problem." However, due to the reasons previously stated, the quality of analytical techniques used by respondents to confirm MIC as a cause, and the lack of investigation after detection and treatment bring the results of this study into question.

The only other related studies/data compilations completed have been conducted by FM Global. In their studies, in losses involving sprinkler systems, corrosion is the fifth leading cause of system failures. This is based on a review of data from 1988 to 1997. In another study by the FM Metallurgical Laboratory between 1994 and 2000 reviewing 155 cases of sprinkler system leaks, MIC was found to be present in approximately 40 percent of cases. Details on whether the presence of MIC directly caused leaks were not indicated in all these cases. [11] And, in another FM study of piping field samples between 1991 and 2002, over 60 percent of these failures are said to be attributed to MIC. [12]

Pinning the Blame

Part of the problem in obtaining detailed conclusive evidence is the complexity and cost of such investigations.

This is also a major point of frustration with owners experiencing these types of problems. Due to the nature of electrochemical corrosion, most corrosion engineers agree that the degree to which MIC specifically increases or contributes to general corrosion can never be conclusively determined. In fact, the complex biological interactions between bacteria and host materials are still not fully understood in many cases. There are simply too many variables and uncertainties that affect all corrosion reactions, especially those involving bacterial interactions. Thus, a percentage of blame or rate of corrosion from MIC likely cannot be numerically defined in any study. And, any database generated at this point will likely list only reported cases, not confirmed cases. Thus, the best that can be achieved in the future is a regularly updated database indicating where reported cases are occurring, method of failure detection, interior condition of pipe, methods of testing, and treatment with future corrosion monitoring.

Materials Affected by MIC

Although steel sprinkler pipe is the typically observed first point of failure, sprinkler orifice caps, control valves, fittings, and supply tanks may also be subject to damage from MIC. Numerous cases of obstructive growth and pinhole leaks associated with MIC have been found within 20 feet of the discharge side of site fire pumps — an interesting phenomenon due to the velocity of waterflow at this point in the system piping. While evidence suggests that only metallic components are susceptible to MIC, it is clear that some grades and alloys of steel are definitely more susceptible than others. As an example, certain grades of stainless steel are more susceptible than regular steel pipe, while others appear to show signs of resistivity. And although plastic components, such as underground water mains, are not subject to direct MIC, they are subject to the effects of biofouling or bacterial debris blockage from upstream corrosion activity.

DEFINING MIC

Oxygen Tolerance

MIC-related bacteria are classified primarily by oxygen tolerance; that is, they are *aerobic* or *anaerobic*. Aerobic bacteria require oxygen to flourish and reproduce. Anaerobic bacteria do not require oxygen to flourish and reproduce. [10] The most damaging MIC appears to take place within a highly complex community with multiple species of bacteria. This community includes not only aerobic and anaerobic bacteria, but also facultative bacteria, those MIC bacteria that function in both aerobic and anaerobic environments. All three types of bacteria can play a role in the somewhat random interactions that can occur in microbiologically influenced corrosion. [13]

Metabolism

In defining MIC bacteria further than previously done, classification is not absolute and can become confusing. The most commonly used method of categorizing bacteria associated with MIC is by metabolism. These categories are basically definitions of what each bacteria type eats (or metabolizes) and excretes as a by-product. 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) to sustain life.

Metabolic classifications are not universally replicated among scientists 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, and iron bacteria. [10,13,14,15]

Scientific Nomenclature

Finally, all bacteria (i.e., all plants and animals) can be classified by their scientific name under phylum, class, order, family, genus, and species. For example, one type of sulfate-reducing bacteria is anaerobic and metabolizes sulfate to sulfide. The sulfate-reducing bacteria group includes the genera *Desulfovibrio*, *Desulfobacter*, and *Desulfomaculum*. [3] All are of the phylum Thiopneutes, which interestingly translates from Greek to ‘‘sulfur-breathers.’’

SOURCES OF MIC INFECTION

Although there are no conclusive relational studies in the fire protection industry, as noted there are growing beliefs that a sprinkler system's water supply is not the only (and possibly primary) source of bacterial infection. Bacteria capable of causing MIC are potentially present in soil, air, and cutting oils, as well as in water. Thus, the manufacture, shipping, storage, and flushing of system materials should be addressed in all MIC investigations. MIC does not occur only in water-filled systems. Dry pipe systems are also susceptible. Dry systems may even be more susceptible to damage than are wet systems, due to the humidified atmosphere that is created after trip testing. A trip test and subsequent drain can create the right atmospheric moisture content for some bacterial colonies to thrive. Complete drainage and the subsequent use of truly dried air or nitrogen gas appear to mitigate this problem. With regard to tubercle growth alone, dissolved oxygen content, not bacteria, may be the only considerable factor in prevention.

MIC CORROSION PROCESS

As with other forms of corrosion, MIC removes material through a series of electrochemical interactions. As such, both an electrical and a chemical component occur with MIC. The electrical component occurs through electron transfer. Electron transfer removes pipe wall material one electron at a time. With MIC, this exact interaction is highly dependent on the specific bacteria involved. Within a sprinkler system, metallic parts become anodic in relation to the cathodic corrosion cell and surrounding water. Basic cathodic depolarization occurs as electrons are stripped away through various forms of oxidation and are pulled to an atom with another electrical potential. Although many of the complex cellular interactions of bacteria are still unclear and can vary by system, there appear to be several somewhat universal steps in the MIC process. They are as follows: [3]

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 by-product that bonds together to form crustaceous nodules called tubercles.
3. Tubercles and associated biofilms create microenvironments on the metallic material surface (under the tubercles). Tubercles are hard protective shells formed by biological activity. Tubercles typically have an open interior fluid cavity over the corrosion floor area with an approximate pH of 3 to 4. (See Exhibit S3.5.)
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. Thus, electrons in the anodic metal flow to the cathode through a reduction reaction.
5. Underdeposit anaerobic bacteria metabolize pipe wall materials and excrete acids (such as acetic acid), as by-products, which are very aggressive to the carbon steels used in sprinkler piping. Relative acidity and alkalinity levels within the tubercle shells are reduced to an approximate pH of 2 to 4, which chemically attacks the metallic component surface.

On painted sprinkler piping, it is common to observe blisters where through-wall penetration has occurred. Testing of the fluid within these blisters has shown a pH of less than 3.

EXHIBIT S3.5 *Interior Tubercle.*

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

PREVENTION AND TREATMENT

References from Allied Fields

Currently, the fire protection industry has a very limited number of directly usable references supported by scientific data. However, there is excellent information on data from other industries. The National Association of Corrosion Engineers (NACE) has published multiple studies about MIC detection and treatment for many years. ASTM (American Society for Testing and Materials) offers several publications on proper bacterial testing practices.

Also, the American Water Works Association (AWWA) offers standards describing the proper management of the somewhat hazardous chemicals typically used in injection devices attached to sprinkler systems for microbial control.

Fire Protection Codes and Standards

The National Fire Protection Association (NFPA) also addresses MIC. NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, discusses MIC treatment, inspection, and detection in some detail. NFPA 13, *Standard for the Installation of Sprinkler Systems*, contains a requirement that provides more guidance. In covering water supply treatment, NFPA 13 states:

> Water supplies and environmental conditions shall be evaluated for the existence of microbes and conditions that contribute to microbiologically influenced corrosion (MIC). Where conditions are found that contribute to MIC, the owner(s) shall notify the sprinkler system installer and a plan shall be developed to treat the system.

Although this requirement has generated curiosity, the resulting questions about effective treatment remain. NPFA 13 indicates that water supplies ‘‘shall be evaluated for the existence of microbes and conditions that contribute to microbiologically influenced corrosion (MIC)’’ and if present or suspected ‘‘a plan shall be developed to treat the system.’’ The who, how, and when are still in debate by those addressing this issue. Who is best 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., with the most technical accuracy and cost effectiveness) to confirm MIC? Almost anything requiring laboratory work can be overtested, and undertesting can lead to a false sense of security. Answers to these questions are still evolving.

Operational Considerations

As the industry continues to develop methods to treat and prevent MIC, building owners are faced with the challenge of managing associated risks to their assets and business operations. At-risk businesses should review the interdependence of various operations to identify critical locations.

Proper Diagnosis

The analysis required to properly select a course of action to address MIC is typically outside of the scope of most sprinkler contractors and engineers. 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 large amount of money can be spent on a problem that may not be correctable. A poor treatment choice could actually accelerate the corrosion rate and increase the affected area beyond that experienced before treatment. The company chosen to determine treatment must have 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 other industrial processes and systems where MIC is typically addressed.

Specific Considerations for Fire Sprinkler Systems

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

Finally, it must again be stated that it is critical to understand that premature system failure can be a function of both bacterial infection and water quality that is incompatible with components. In the majority of premature system failure cases, water chemistry or poor design may be the only likely factors requiring consideration. A high bacterial count does not always indicate that 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 again in the near future.

Detection in Existing Systems

In existing systems suspected of 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. Although current technology makes this detection easy, analysis of the 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 or are necessarily needed. Current preferred analysis methods run the spectrum, depending on the consultant chosen. Costs for such testing can also vary widely.

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 cost/benefit decision requires further study and is not supported one way or the other by documented best practices in the fire protection industry.

Pipe cleaning is typically an option when corrosion (i.e., pitting) is not excessive. However, "excessive" is a relative term. The after-cleaning quality of the pipe must be considered, for both 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. When replacement materials are chosen that are different from those of the original system, they must also be accounted for in hydraulic analysis of the posttreated system. Case studies suggest that pipe cleaning may remove corrosion by-products that are, in effect, stopping the flow of water through existing pipe penetrations, subsequently resulting in leaks. [13] Prudence dictates that complete mitigation must include some form of treatment once pipes are cleaned.

Prevention in New Systems

In new systems, it is critical that susceptibility be determined before any systems are filled or tested with any water. If water tests are positive for MIC-related bacteria, a chemical injection system must be installed and used from the first fill. This includes hydrostatic testing and preliminary fills. The treatment methodology must also consider that water delivery of treatment chemicals might not effectively treat high spots, remote areas, or areas that trap air within the system.

If MIC is anticipated, one form of risk reduction may be to specify thicker piping in the design. Although this option only tends to buy time, it may serve as a prudent measure until universally accepted treatment methods are developed. Thicker walls buy time, not because they are less susceptible to MIC — a point on which evidence to date is inconclusive — but simply because a thicker wall has more material to corrode before a through-wall leak develops.

Another possibility in design is to remove the risk of leaks before MIC treatment is even evaluated. Areas such as those occupied by critical energized equipment can often be addressed by removing overhead sprinkler piping and limiting leak exposure through use of sidewall sprinkler coverage. Where it is not feasible to relocate large feed mains, piping can be sleeved so as not to permit potential leaks to contact energized equipment. Although these efforts provide some measure of immediate relief, they do not address the root cause or present a long-term solution to the problem.

Finally, the frequency of sprinkler and waterflow device testing must be addressed. Most agree that repeated draining and refilling of sprinkler systems can increase both biological and nonbiological forms of corrosion. Draining and refilling provide nutrients and oxygen to bacterial colonies and oxygen for general tuberculation. Some facilities have noted substantial reductions in the frequency of leaks by reducing the frequency of drain and alarm testing.

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

Chemical Injection

Once system components have been cleaned and sterilized or replaced, 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.

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. At the time of this writing, none of the systems currently available was believed to be specifically listed or approved for use as a sprinkler system component. Although most systems appear to be effective when properly installed and maintained, reliability and effectiveness have not been time-proven when compared with other 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 bacteria believed to be related to MIC (such as the genera *Bacillus* and *Clostridium*) are known to have the ability to convert to a spore state when they encounter adverse conditions that are not lethal. [3, 16] Spores are impervious to penetration by most chemicals and can thus survive biocide treatments indefinitely. Although subsequent treatments may slow or stop their activity, spores will reappear if and when treatments are stopped, and resume colonization. With a weak chemical attack, bacteria may also become resistant to the chemicals chosen.

As with other factors involved in treatment, the choice of chemical depends on the consultant. These chemicals generally include penetrants and biodispersants to break up the tubercles that protect underdeposit colonies, a biocide to kill the bacteria in the colonies, and a corrosion inhibitor to protect the interior surfaces of the system.

When such a system is chosen, the applicable authority having jurisdiction (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 pressure drop of 10 psi (0.7 bar) or more to sprinkler systems in addition to that created by pitting if cleaning is chosen. In new system designs, added alarm system contacts should also be planned for to monitor injection system chemical levels, operational status, and trouble conditions such as loss of power. Many pre-engineered systems provide contact points for these signals. As with fire detection, the perceived "best choice" is at the discretion of the person choosing, and opinions on this subject are highly variable.

Unlike other industrial systems treated for MIC, several unique interactions must be considered. First, sprinkler systems are typically located directly over people. The chemicals used must therefore be nontoxic in contemplation of accidental discharge or exposure to fire fighters under fire conditions. The effect of chosen chemicals on fire fighting (i.e., heat absorption) and chemical reaction with fire (i.e., heat) also needs consideration. Second, system designs typically place water discharge (such as from an inspector's test ports) into foliage or biologically sensitive drains and dry wells. Most municipal wastewater 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 chemicals must also be nondeteriorating to rubbers and polymers such as those used on pipe couplings, sprinkler o-rings, and valves. Chemical storage should also be reviewed, as several chemicals currently in use degrade rapidly with heat and may create relatively toxic vapors.

Opinions of which chemicals are believed to be "most effective" in control vary. Choices are available from those currently used for treatment in cooling towers and boilers to specifically patented compounds for fire protection systems. Some of the more common chemicals currently in use specifically for microbial control in sprinkler systems include quaternary ammonium compounds, organosulfur 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 for sprinkler plugging that overdosing can cause. At the writing of this article, no chemical can conclusively be said to be proven as the "most effective." The chemical choice may greatly depend on the bacteria present and system water quality.

SUMMARY

Current testing and treatment options can be confusing. Treatment is slowly evolving and research is continuing. Several industry groups, allied groups, and insurance companies are looking at the problem and applicable solutions. Many universities, governments, and private industry groups also continue to research microbial control in general industry, as they have for the past several decades. These efforts will continue to provide improved treatment options in our industry.

As the need to address this problem draws on the industry's creativity for resolution, prudent thinking requires us to evaluate each solution's impact on overall sprinkler system integrity and performance. In light of this problem, the overwhelming value of sprinkler systems should not be regarded as tarnished or tainted. Although some with repeated MIC problems may view sprinklers as a risk to property, the reduction of risk to life and property from fire these systems provide should never be overshadowed.

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NFPA Codes, Standards, and Recommended Practices

Reference to the following NFPA codes, standards, and recommended practices will provide further information on microbiologically induced corrosion in fire sprinkler systems discussed in this chapter. (See the latest version of the NFPA Catalog for availability of current editions of the following documents.)

NFPA 13, *Standard for the Installation of Sprinkler Systems*

NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*