Biofilms/Corrosion Survey in Water Pipes

Lawrence S. Galowin
larrygales@earthlink.net
Consultant

Abstract

A literature survey on problems in building water pipes concerning corrosion processes, deposition/removal of biofilms, and materials/formations was made. Pipe walls' hazardous biofilm attachments and techniques for removal of microbiologically induced corrosion (MIC) are now commercially available. Past studies of MIC and copper pinhole leaks in water pipes on wall corrosion have brought specific methods for cleanout techniques. Investigations also relate applications to removal requirements of hazardous materials from slimes and biofilm formations. Such concerns can offer input to determinations for viral-bio-radiological selected agents that represent hazardous states. Pinhole leaks in pipes may be attributable to biofilms as causative aspects in pipe deterioration. Recovery of building potable water systems from natural disastrous events (hurricanes, tsunami, and earthquakes) requires similar considerations. Formations of corrosion products tubercles relate to varieties of failures that includes leakages, pipe blockages and other biological formations that cause upset conditions and threaten building water quality. Slime in systems from hazardous aftereffects (hurricane in New Orleans area) may require special cleaning of contaminants by valid and also unproven methods. The breadth of concerns for elimination of hazardous biofilms attachments including viral-bio-radiological selected agents may be advantageously derived from prior research.

Keywords

Building potable water systems; plumbing water pipe systems, biofilms, biological pipe wall attachments, building water contamination, fouling, pinhole leaks, microbial corrosion.

1. Introduction

Historically, many aspects of biofilm corrosive attacks problems have been of concern for ships, industrial processes, petrochemical, gas and nuclear power industries.

Impacts range from mechanical blockages, reduced flow capacity, wall penetrations and leaks and recent investigations have focused on copper pipe pinhole leaks in buildings. Tuberculation elimination with suppression of localized conditions that reduce 'pitting-type' attack has been demonstrated in removal methods for wet fire sprinkler systems but apparently differ as dependent on fields of applications.

Research applicable to this study was sought for application potentials from understanding developments from microbiologically induced corrosion (MIC). Biofilm 'biofouling' information was found (e.g., internet search references). Usual definitions found in many sources indicate {a partial excerpt}:

> Biofouling occurs worldwide in various industries, from offshore oil and gas industries in China and the Indian Ocean, to fishing equipment in the Caspian Sea, to cooling systems in the Chesapeake Bay. Most common biofouling sites are hulls of ships, where barnacles are often found. The most obvious problem of growth on a ship is the eventual corrosion of the hull, leading to the ship's deterioration. Even before corrosion occurs, if left unattended, organic growth can increase the roughness of the hull, thereby decreasing its maneuverability and increasing drag. This domino effect continues when the ship's fuel consumption increases, in some cases by 30%. This in turn has economic and environmental consequences, as increased fuel consumption leads to increased output of greenhouse gases. Economic losses are tremendous, as fuel accounts for up to 50% of marine transportation costs.
>
> Biofouling is everywhere. Parts of a ship other than the hull are affected as well: heat exchangers, water-cooling pipes, propellers, even the ballast water. Heating and cooling systems biofouling might also be found in power stations or factories. Just like a clogged drain in your kitchen or bathroom, buildup of matter inside cooling system pipes decreases performance. Again, fouling causes a domino effect. Equipment must be cleaned frequently, at times with harsh chemicals, and the obstruction of piping can lead to a shutdown of plants and economic losses.

Other excerpts (1) illustrate variety and ranges of interests:

- Causative factors responsible for contaminant biodegradation with investigative research on cause's bioremediation of individual compounds and with mixtures of toxic compounds with a range of recalcitrance. The study is using specially designed microelectrodes and development of a permeable biowall system for bioremediation.

- Effectiveness of Chlorine Dioxide in the Disinfection of Biofilms in Pipes and Food Process Equipment. The food industry concerns for microbial contamination in pipes and process equipment results from microorganisms attached to solid surfaces. Biofilms represent significant health risk because they can harbor pathogens, and direct contact can lead to food contamination. Biofilms are notoriously resistant to many disinfectants, which often react with extracellular polymeric substances (EPS) and other organic constituents that form the biofilm, thus inactivating the disinfectant. Disinfectants may not reach bacteria in the biofilm that may proliferate after disinfection. Effectiveness of a disinfectant used for biofilm control can be determined by measuring the rate and depth of disinfectant penetration.

- Potential for Pathogen Adhesion to Water Distribution System Biofilms Following a Bioterrorism Attack. Simulations for mechanisms of adherence and retention of fouled iron surface of a pipe wall to which pathogenic cells injected into a model distribution system are being applied. Water distribution systems are vulnerable to intentional contamination and accessible with basic understanding of water supply networks. How biological agents interact with the distribution system, especially the corrosion and "fouling biofilm" located on the pipe wall is required. Chlorine residual in the water may inactivate many planktonic organisms but the fate of organisms trapped within the biofilm is unknown. If pathogens adhere and chlorine residual is ineffective then biofilms may serve as a reservoir for pathogenic microorganisms.

- Drinking water building systems concerns for corrosion and scaling phenomena that impact quality and increase development of bacteria have led to development of determination of degradation risks (2). The methodology applied for development of risk analyses determinations of several deterioration elements for galvanized and copper pipe materials was discussed. Utilization classifications at three levels of degradation by applying techniques from quantification methods to applications were indicated by computer aided assessment tools. An alarm system for building managers information on water system functions that may intervene before degradation was also suggested.

Biofilm materials consist of an organic slime produced and containing bacteria. Slime protects the microbes from the environment and helps them stick to surfaces. Biofilms form on many surfaces under water and is independent of whether surface materials are biological. Such films are found in stagnant and flowing water when nutrients are present. Biofilms are formed on stones where water flows and appears on metal, wood, particles or anything solid. The films function as systems that degrade organic compounds and transform inorganic ones. Biofilms can be useful in nature since they absorb pollutants and reduce buildups by degrading them; in human intestinal tracts provide protection from disease-producing organisms. Applications include usage in sewage and waste water management where trickling filters and bed reactors use biofilms to break down and transform sewage and waste waters. In industrial plants they help in breaking down pollutants as fuels to reduce bacteria and toxic contaminants. Bacteria are buried in the slime so that antibiotics and other chemicals may not act and avoid destruction.

Pinhole copper pipe destructive elements have seemingly not been associated with identified biofilm formations; studies for causative factors lean toward physical electro-chemical aspects leading to pinhole sites development. Chemical deterioration factors have most often been related in explanation of those phenomena.

Potable water quality water restorations are required in many circumstances that result from natural or man-made disasters. Focus was on contamination/corrosion formations that cause clogging blockages, leaks, and potentials relating to terrorist enigmatic causes for safety of potable water quality in buildings. Other applications to building water systems also apply for recovery from earthquakes and hurricane induced hazards.

In this review fundamentals were sought that govern establishment and growth of wall attachment processes of biofilms, tubercles, and for descriptive analyses of attachment mechanisms from bio-viral-chemo attack on usual piping materials. Wall deterioration studies of attachment phenomena provide for techniques and methods adaptable to clearance in restoration of quality water distribution systems. Elimination of copper pinhole leaks could benefit from understanding phenomena at pipe walls. Advantageous clearance methods from prior MIC investigations of impacts on causes of wall corrosion provide information related to eliminating impacts on building water distribution systems. Biological fouling prevention and/or maintenance requirements of fire sprinkler systems have become obligatory by National Fire Protection Association (NFPA, 3).

2. Information - Interfaces

Preservation of potable water quality water following deterioration from introduced materials can threaten public health and is a vital concern. Serendipitous opportunities exist from studies on potentials for removal of contaminants by linking known explanations of biofilms' research sectors applicable to recovering building water piping systems. Also, potable building water supply foreboding has arisen from hurricane damage flooding of buildings in recovery concerns. Wall attachment materials from known and unknown compounds from terrorist attack with viral/bio/chemo hazardous materials can result in pipe wall cavities residual masses that may later burst into the flow and form other wall attachment mechanisms. Study efforts are required for development of methods applicable to their removal and elimination of persistent conditions. Clamps shown eliminate dripping (4) as communities experience copper pinhole leakages (reported in internet communications). Understanding depositions on water pipe inner walls may provide insights of governing factors in copper pipe pin-hole leaks to situations illustrated.

State of Maryland
Final Report: Task Force to Study Pinhole Leaks in Copper Plumbing

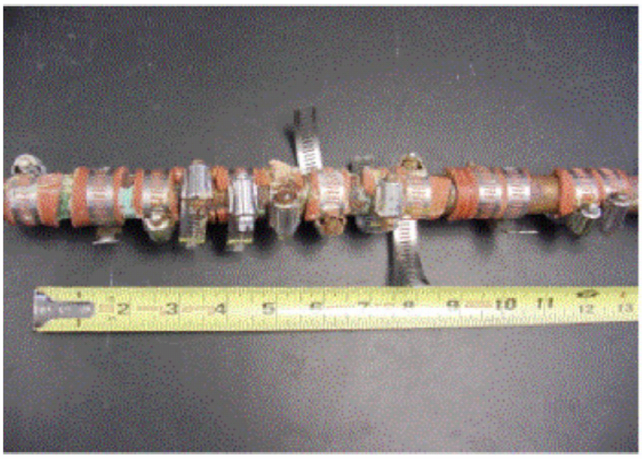


Figure 9: Pipe from Arlington, Virginia Water System with Clamps to Stop Pinhole Leaks (Courtesy Dr. Marc Edwards)

Telephone discussions with specialists in biofilm MIC research studies shared the conceptual idea that their information can apply in providing insights and understanding for applications to building potable water systems. Extension to current concern for descriptors of biofilm impacts appear common to both problems. Reports from diverse sources have similarities on biofilm information impacts. Potentials appear for health/safety aspects tracing to corrosive deteriorations and material failures due to the 'foreign depositions of microbiological characteristics' and destructive contamination. Particulars are available in research listings from U. S. 'Center for Biofilm Engineering', Montana State University (1).

Citations on bacterial biofilm ranges from formation of plaque that forms on teeth (causes tooth decay) and extends to "gunk" that clogs drains, and also as readily observed on coated rocks at lake edges and piers where biofilms develop. Surface bacteria adherence in aqueous environments indicates biofilms resulting from excretion of slimy, glue-like substances that can anchor to all kinds of materials. Examples include metals, plastics, soil particles, medical implant materials, and tissue. Formations can result from a single bacterial species but mostly consist of many bacteria species. Suspect materials may be recognized from other discolorations and/or as fungi, algae, protozoa, corrosion products and debris. Fundamentally, any surface exposed to bacteria and some amount of water can cause formations of biofilms. Dependence on surrounding environmental conditions anchored materials on a surface may result in detrimental or even beneficial reactions of biofilm microorganisms. Several suspect **organisms may cause biofouling and water contact for a period of time results in organism attachment to surfaces.**

From a study – "Potential for Pathogen Adhesion to Water Distribution System Biofilms Following a Bioterrorism Attack". Simulations for mechanisms of adherence and retention of fouled iron surface of a pipe wall to which pathogenic cells injected into a model distribution system are being applied. Water distribution systems are vulnerable to intentional contamination and accessible with basic understanding of water supply networks. How biological agents interact with the distribution system, especially the corrosion and "fouling biofilm" located on the pipe wall is required. Chlorine residual in the water may inactivate many planktonic organisms but the fate of organisms trapped within the biofilm is unknown. If pathogens adhere and chlorine residual is ineffective then biofilms may serve as a reservoir for pathogenic microorganisms.

3. Framework - Findings

Observations and analyses of inner pipe walls at biological corrosion sites show attachments to the metallic surfaces of tubercles and their distributions of organisms that cause corrosion, blockage and pitting holes in destructive pipe failures. Observers indicate microbial communities in local depositions are attributed to varieties of mechanisms associated with differential oxygen cells, under-deposit chloride concentrations, sulfide attacks, and aspects of acid production. Most investigators indicate microbial corrosion does not occur in absence of biofilms although essential mechanisms apparently vary due to materials and surface conditions in water that cause pitting and deterioration in pipe systems. Causative factors always appear associated with presence of slime and tubercles caused from biofilm formations in ‘attacks’ on inner pipe walls. The Copper Development Association (CDA) provides problem references (5) but lacks remediation techniques for prevention. Pin-hole leaks in building potable water copper piping have not been traced to specific causative actions.

The report {required by Maryland State Senate (4)} on the pinhole leak phenomena and deal with its consequences indicated no identifiable specific causes but limited potentials for mitigation were shown. Indicated probable actions from material impurities in copper pipes were found but the specifics of deterioration modes remained undetermined. Water supply/treatment parameters or/and installation methods were a main concern. Causative deterioration formation was not resolved although examined samples displayed similarities to MIC. Three activities considered were water treatment, materials, and insurance (costly restorations). The findings were that no specific cause was determinable but research on mitigation and determinations from on-going research may be anticipated. Copper water pipe sample photographs indicated very similar distinguishing aspects to features from deteriorated sample fire sprinkler pipe MIC sections. Photos suggest formation of tubercles on the pipe wall as commonly found in such studies of water filled fire sprinkler pipes.

State of Maryland
Final Report: Task Force to Study Pinhole Leaks in Copper Plumbing

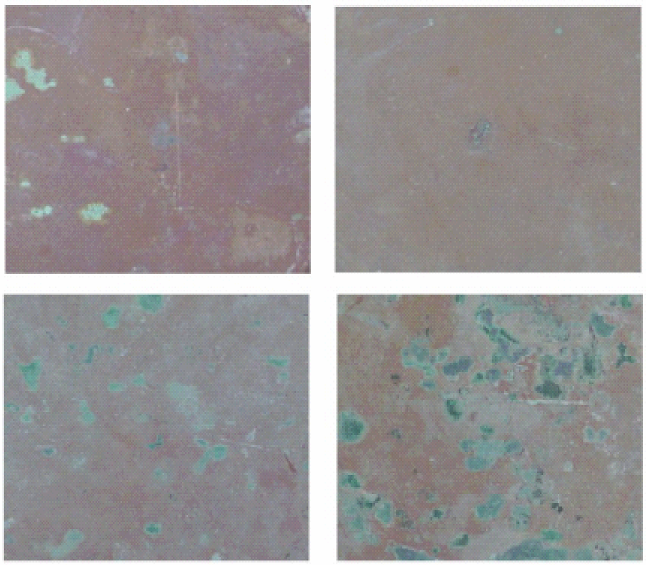


Figure 10: Dried Copper Surfaces After 6 months' Exposure to WSSC Water and Aluminum Solids

The top left picture is with water with 0 mg/L free chlorine. Top right: 1.2 mg/L free chlorine. Bottom left: 2.4 mg/L free chlorine. Bottom right: 3.6 mg/L free chlorine. All samples were exposed to 30 mg/L aluminum solids. Surface areas of each picture are approximately 100 cm^2 or 12 square inches. (Courtesy of Dr. Marc Edwards)

3.1 Prevention Actions

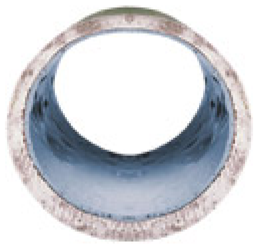
The Washington Suburban Sanitary Commission (WSSC) has recently applied an orthophosphate chemical additive (phosphoric acid, an EPA approved additive product) to counteract pinhole leaks. The additive can form pipe wall protective coatings which presumably resist attack on the copper pipes. Sufficient time for development of the wall coating is required to determine if the additive fulfills the protective need. Some communities have not approved such practices.

Prevention of pinhole leaks by a protective pipe wall coating has become commercially available from commercial contractors. Typically, renovation requires inner pipe wall cleaning by an abrasive material injected into the system and followed with an epoxy like coating material spray that coats and protects inner walls {method derives from other countries experiences} and decade guarantees are made against further pinhole leakages. Such coatings are advertised also as a preventive maintenance procedure.

Illustrated pipe sections and excerpts are shown {commercial advertisement (CuraFlo™ epoxy lining process)[*]}.

”…… advanced alternative to the traditional approaches of repairing corrosive or leaking pipes. Pipelining is a cost effective method that coats the inside of the pipe with a durable and safe epoxy. The epoxy is applied with minimal disruption to the property and is often less costly than the traditional repiping alternatives.”

Unlined Pipe



Epoxy Lined Pipe

The {ACE DuraFlo™ [1] system} of pipe restoration is designed to clean the piping system of encrustation build up and then coat the interior of the pipe with a NSF Standard 61 approved epoxy coating material, stopping any future water to metal contact. The size of pipes that can be restored using this process can be as small as 1/2” in diameter. Application within buildings has ranged from smaller walk-up style apartments to high rise facilities. The system of pipe restoration is applied to pipes within the walls eliminating the traditional destructive nature associated with a re-piping job. Typically, 1 riser system is isolated at a time and the restoration of the riser system is usually completed in 1 day with water restored the next day. Too, there are no walls to cut no large piles of waste and no dust. Savings in time and costs when compared to a re-pipe are striking. Piping systems are typically restored in ½ the time and with 30% to 60% cost savings over a repipe job.

The epoxy coating creates a watertight barrier on the interior of the pipe and prevents the water from actually coming in contact with the metallic surface of the pipe. Not only repairing the effects of corrosion but providing the best possible solution to stopping corrosion from reoccurring!

Epoxy coatings are characterized by their durability, strength, adhesion and chemical resistance, making them an ideal product to coat or line the interior of existing or even new piping systems. As a form of corrosion control, epoxy coating is recognized and used by both the County Sanitation Districts of Los Angeles County and in the San Francisco region, the East Bay Municipal Utility District. Durability - pipe restoration coating material (epoxy) properly applied will be expected to give an effective life of at least 75 years. Epoxy lining materials used in drinking waterlines are subject to

[*] Citation(s) **are not recommendations**; provides only illustration of a commercial method.

strict health guidelines laid out primarily by the National Sanitation Foundation (NSF) with widespread North America acceptance from regulatory communities.

3.2 Insights & Conjectures

Similarities of potable water piping copper pin-hole leak experiences with MIC leakages and destructive pipe failures from corrosion pitting holes, or blockage/stoppages, leads to an hypothesis for correlations between those phenomena. Techniques from cleaning/maintenance of MIC's have not focused on technology transfer for repair/renovation to potable water systems. Related issues resulting from scouring pipe walls has not been evaluated for total eliminations of residuals, especially at pipe size change 'steps' or at valve obstructions where lurking residuals may be encapsulated with unknowns for dislodgement and reentry into the water flow (e.g., valve seats, fixture controls, and any other plumbing system impediments) where streaming smooth flow conditions do not prevail.

Microbiologically Influenced Corrosion (MIC) investigations of fire sprinkler piping systems deterioration have determined sources of corrosion relate to the presence of microbial activities but initiation processes and environments essential for development remains largely unknown. Tubercles distributions of organisms attached to the metallic surfaces at biological corrosion sites were locally observed at depositions where microbial communities' growths occur.

Causative factors that induce deterioration effects on inner pipe walls always appear associated with presence of slime and tubercles caused from biofilm formations. Attribution by investigators relate varieties of mechanisms associated with differential oxygen cells, under-deposit chloride concentrations, hydrogen sulfide generation, sulfur-oxidizing and sulfide attacks, sulfate-reducing, iron-oxidizing, acid-producing, and nitrate-reducing bacteria and aspects of acid production. Subsequent development of differential aeration cells can lead to deterioration and failure of mild steel, copper, stainless steel, and other ferrous and non-ferrous metals used in construction. Plumbing systems extension to galvanized and plastic water supply piping in many buildings may develop comparably similar, although different pipe wall materials may result in other slime and biofilm compositions from copper usages and have potentially other threat scenarios.

Under-deposit pitting often results in pinhole leaks that may occur within months of new installation. At later times, where slimes, discrete deposits, and pinhole leaks develop telltale signs of MIC. Frequent exposure to MIC factors increases the likelihood of ***severe*** MIC. However, an essential mechanism involved varies due to materials and surface conditions which induce formations. Varied potable water supply conditions and quality treatment methods impacts on constituents and remain as unknowns for induced pitting and deterioration in pipe systems.

Of special interest is an observation that presence of microbes does not result in MIC unless those listed factors appear. Causative factors 'attacks' on inner pipe walls always appear associated with presence of slime and tubercles caused from biofilm formations. These suggest sufficient indicators related to pinhole leaks in water distribution systems. Other unknowns remain for potential impacts on non-metallic type materials, e.g., plastic piping materials attack in concerns for plastic piping related to chlorine withstand and/or exposure to ultra violet exposures that may be adapted to clearance actions.

Adaptations from known commercially available treatment methods may provide economical and practical recovery in pinhole protective actions and purging recovery from hazardous materials. Measurement(s) means suitable for assuring clearance to human user needs with significant reliability is essential. Presence of hazardous materials by particular identifications may not be essential for clearance requirements but assurances that safe quality must be of established adequacy in clearing potable water systems is paramount

The following excerpted information (5) provides descriptors and micro-photos {source approved}. The findings suggest slime on walls as potential lodgment sites for many varieties of contaminants in attacks on building water supply systems. Such information sources offer understanding that leads to potentials of clearing and restoring quality potable water after disaster events that contaminate water delivery systems in buildings.

Figure 2. Bacterial biofilm associated with stainless steel tube. Scanning electron micrograph magnification at 5,000X.

Inner pipe walls attached formations is shown in the micro-photo (21) of MIC study of fire sprinklers; the author indicated ".. little is known about the role microorganisms play in initiating or propagating physicochemical corrosion processes …". Further - "…tubercles can completely occlude pipes, and more significantly, these deposits can break off and block sprinkler head flow channels. Localized pitting-type attack can also occur underneath tubercles, resulting in through-wall penetration. The resulting acid production, hydrogen sulfide generation and development of differential aeration cells can lead to the loss of essential metallic properties of mild steel, copper, stainless steel and other ferrous and non-ferrous metals." Causes are dubious "… bacterial biofilms are the initiating and/or propagating agents of MIC; microbial corrosion does not occur in the absence of biofilms. Biofilms provide localized environmental conditions (decreased pH; differential oxygen cells) initiating or propagating corrosion activities."

On causes and effects "… mechanisms include development of differential oxygen cells, under-deposit (biofilm) chloride concentration, and sulfide-mediated attack, acidic dissolution of corrosion products and cathodic depolarization of protective hydrogen films. While corrosion of copper piping may present an environmental and economic threat in both fresh water and seawater systems, relatively little is known of the role microorganisms play in initiation or propagation of corrosion events. It is known, however, that bacterial biofilms are the initiating and/or propagating agents of MIC; microbial corrosion does not occur in the absence of biofilms. Biofilms provide the localized environmental conditions (e.g., decreased pH; differential oxygen cells) for initiating or propagating corrosion activities."

Sulfate-reducing bacteria can cause rapid pitting of 316 SS base metal and welds, leading to through-wall penetration. MIC mechanisms for stainless and mild steels (incompletely understood) usually involve acid production or sulfide-attack. Researchers have described bacterial biofilm-mediated attack of copper in both controlled laboratory experiments and in field studies of tubing in hospital water systems. The slime produced by bacteria may also be important in the dissolution of corrosion products, leading to an increase in corrosion rates.

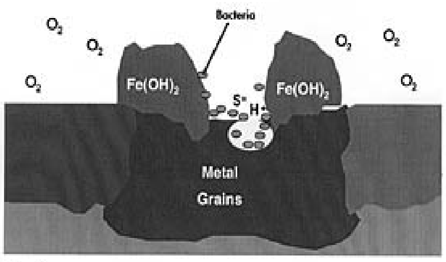
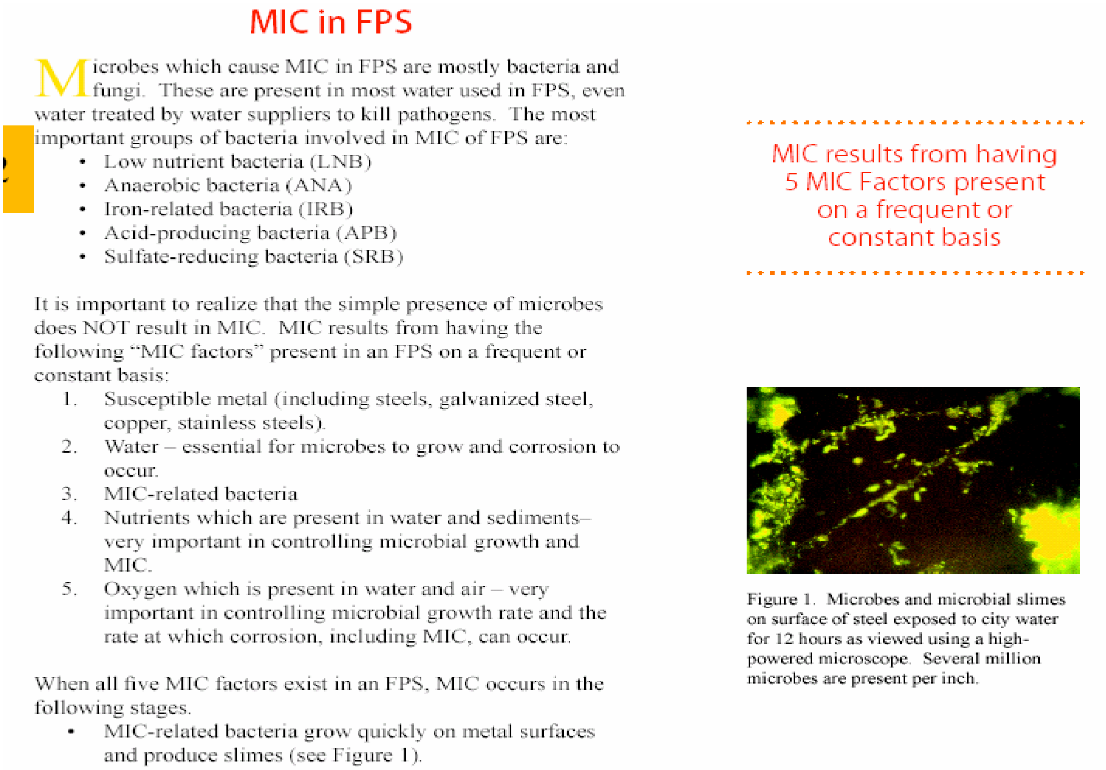


Figure 3b.

Figure 3b. MIC resulting in acid production and sulfide generation leading to pitting-type attack.

Other resource discussions appear on stagnant water in pipes that showed disappearance of chlorine from the treatment supply plant and thereby no longer provide protection from bio-micro formations. Limited public literature provides for concerns of hazardous impacts that result from attachments/growths at deposition sites for wall attached bio-viral-chemo agents and other potentials from unusual or atypical materials. However, there is no attention to standing or stagnant durations from protective actions of additives as chlorine. Duration of chlorine or similar materials applied for delivery into buildings may not have any concern due to flowing conditions encountered in potable water systems piping. In newer concerns from potentials for attacking water delivery systems, or from earthquakes and hurricanes, similar issues may have emerged for concerns in clearing and eliminating life/death hazardous materials from wall attached sites.



MIC in FPS

Microbes which cause MIC in FPS are mostly bacteria and fungi. These are present in most water used in FPS, even water treated by water suppliers to kill pathogens. The most important groups of bacteria involved in MIC of FPS are:

- Low nutrient bacteria (LNB)
- Anaerobic bacteria (ANA)
- Iron-related bacteria (IRB)
- Acid-producing bacteria (APB)
- Sulfate-reducing bacteria (SRB)

It is important to realize that the simple presence of microbes does NOT result in MIC. MIC results from having the following "MIC factors" present in an FPS on a frequent or constant basis:

1. Susceptible metal (including steels, galvanized steel, copper, stainless steels).
2. Water – essential for microbes to grow and corrosion to occur.
3. MIC-related bacteria
4. Nutrients which are present in water and sediments– very important in controlling microbial growth and MIC.
5. Oxygen which is present in water and air – very important in controlling microbial growth rate and the rate at which corrosion, including MIC, can occur.

When all five MIC factors exist in an FPS, MIC occurs in the following stages.

- MIC-related bacteria grow quickly on metal surfaces and produce slimes (see Figure 1).

MIC results from having 5 MIC Factors present on a frequent or constant basis

Figure 1. Microbes and microbial slimes on surface of steel exposed to city water for 12 hours as viewed using a high-powered microscope. Several million microbes are present per inch.

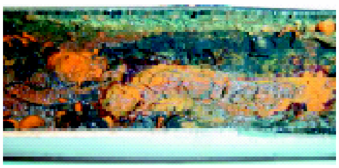


Figure 2. Discrete deposits on interior of steel pipe. These deposits are formed by microbes depositing materials from water and by the accumulation of corrosion products.

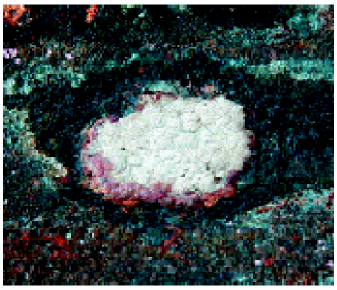


Figure 3. Under-deposit pitting corrosion showing distinct pits-within-pits, which are characteristic of MIC. This type pitting can occur at 0.200" per year and can penetrate FPS pipes within a few months after installation.

- The growth of bacteria ultimately results in the formation of discrete deposits (a.k.a. tubercules or carbuncles; see Figure 2).
- MIC-related bacteria create conditions (principally by producing acids and consuming oxygen) that promote very rapid under-deposit pitting (localized) corrosion (see Figure 3).
- This under-deposit pitting often results in pinhole leaks, which sometimes occur within months of new FPS installation (MIC has been documented to penetrate FPS metals at rates up to 0.200" per year; see Figure 4).

Slimes, discrete deposits, under-deposit pitting, and pinhole leaks are all telltale signs of MIC.

More frequent exposure to MIC factors increases the likelihood of ***severe*** MIC. Therefore, only those ***usually small*** portions of the FPS where MIC factors are present frequently—due to the way the FPS is constructed and operated—suffer ***severe*** MIC. In wet FPS, these areas are typically in: a) larger diameter, horizontal pipes which see frequent water flow and accumulate sediments, and b) in pipes containing air pockets (usually at high points in the FPS—see Figure 5). In dry/preaction FPS, severe MIC is most often seen in horizontal pipes which are likely to accumulate moisture and/or water puddles and sediments (usually at low points and areas adjacent to grooves and fittings—see Figure 6). It is now recognized that frequent flow of untreated water into an FPS—due to retrofits, flow tests, and inspectors' tests performed at remote locations—can contribute to rapid MIC in some portions of an FPS. Reducing the frequency of flow tests and performing flow tests at the riser help prevent MIC. Treatment of waters entering the FPS with agents to prevent microbial growth and reduce oxygen levels in the water is ESSENTIAL to controlling severe MIC.

3.3 Commercial Practices

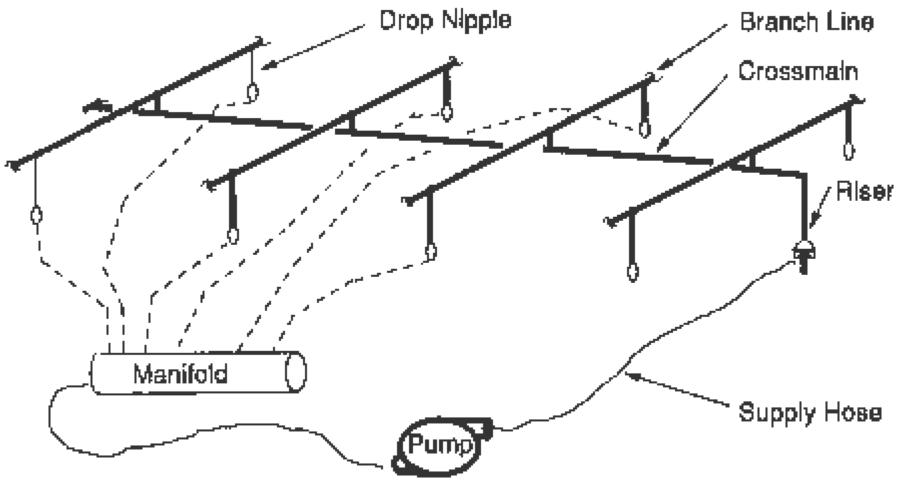
Fire protection water systems clearing are provided by commercial services; those have applications to other water systems. An example (contractor report) on clearing fire protection systems at the McCarran International Airport, Las Vegas, Nevada (6) appears in a case study. A terminal with unusually high number of pinhole leaks fire sprinkler system (less than 10-year-old) and technicians noticed a significant amount of internal buildup of tuberculation nodules in the piping. Use of the PIPE-KLEAN® fps (patent pending) cleaning process was applied to chemically rehabilitate the standpipe system in the International terminal†. The laboratory results (at corporate laboratory) from testing the internal buildup showed MIC problems with high levels of iron, as well as aerobic and sulfate reducing bacteria present.

An isolated circulation loop (sketch for purging sprinkler system shown) pumped the "PIPE-KLEAN C" cleaning solution through the standpipe system, circulated for approximately two hours to remove the MIC/internal buildup. Process monitoring of specific gravity, pH and total dissolved solids during the cleaning process tracked the cleaning progress; scanning pipe interior ensured that buildups had been dissolved and removed. Spent cleaning solution was evacuated from the system, neutralized, and discharged to the sanitary sewer with appropriate local regulatory approvals. The cleaning solution chemistry is a low pH, aqueous organic biocleaner with dispersants

† Product specific/contractor endorsement **is not implied and provides only an example** of commercial practice.

and inhibitors certified to ANSI/NSF Standard 60 (use in potable water systems/applications).

Figure 1: HERC's patented Mobile Recirculating Unit allows cleaning chemistry to circulate through the system.



Requirements were not identified for assuring extent of satisfactory cleansing and ascertaining extent of partial or complete decontamination for restoration to normal service conditions. Presumably, experiences from methods applied to sample analyses following pre-set completion time(s) for flushing cycle(s) of the cleared system determinations were established.

3.4 Other Fundamental Perspectives

The International Conference on Microbiologically Influenced Corrosion (7) convened experts covering diverse mechanisms on many impacted materials that results in many deleterious influences in the built environment. Aqueous environments that influence the surface chemistry on materials affected by microorganisms which results in catastrophic engineering consequences were themes of presentations. Limited efforts were reported for remedial actions in elimination of copper pinhole leaks in building water systems. Understandings of wall attached biofilms structures from research involve varieties of foreign hazardous materials; however, effective elimination of hazards to potable water quality was not a concern. Relevant summaries from studies follow.

Experimentally determined conditions on pitted copper pipes indicates direct relation with biofilm formation and resultant damaging conditions with field test pipe samples (8). Aspects of pitting in copper pipes of three types noted involvement of microorganisms dates back to 1948 (Rogers). Identified conditions with pitting that prevailed include products of metabolism, e.g., anaerobic sulphate reduction, extracellular acids, secretion of organic sulpher containing compounds, ammonia, and ‘slimes and microbiological deposits’. Sample bacterial growth measurements were undertaken; predominant organisms isolated and identified characteristics were determined. Scanning electron microscopy showed association between presence of bacteria and extracellular materials over corrosion surfaces where more active pitting occurred. Apparent susceptibility of organisms to presence of copper ions is known but some resistant populations even exist with associated biofilms having varying tolerances in the states and dissolutions of water systems and active in the corrosion process.

Experimental deterioration investigation of copper corrosion in the presence of extracellular polymers altered the corrosion rate measured five-fold increase in copper corrosion in presence of bacterium (9). Copper from substratum was found to be bound up within the biofilm and not released into solution. The copper-tolerant bacterium on glass slides concentrated the metal ions from solution. Apparent immobilization of the copper ions within the biofilm occurred from the damaging bacterium and accelerated corrosion may be related to presence of exopolymers.

Incidences in a hospital system of copper pipe failures from pinhole leaks were investigated by laboratory failure analyses of damages that were primarily in cold water horizontal pipe sections (10). Local formations of pustels found were comprised of solid corrosion products mixed with crystallized corrosion products. There was a uniform attack detected under the metallic surfaces after applying pickling techniques. Where pustels were noted pitting attacks led to perforations of the copper pipes. Determinations from chemical analyses revealed that prosthetic disaccharides and hydroxol group with serine and lactate could be detected within the corrosion products leading to microorganisms as the reason for corrosion damages. Installation purification of the pipe system was undertaken by circulation of citric acid (at 10 %) overnight and disposed. Few added perforations followed within days presumed to result from stopped up small pits; no further perforations occurred for a year after treatment. After more than a year installed plastic piping (elsewhere) eliminated similar renewal of problems. Positive long term cleaning other than citric acid appears necessary since later examined copper tube samples did show severe attack remains. Test loops for long term studies were set in place.

4. Perspectives and Significance

Focus on wall attached materials and mechanisms involving deteriorated reliability to practices protecting potable water quality were made. The search included water utility sources and plumbing system established requirements for required procedures, methods, or organized elements in specific requirements for potable water. In the U. S. local control authority exists for many water regulatory aspects whereas national governance is practiced elsewhere.

The existing building inventory includes many materials applied to piping systems from impacts of older or newer regulatory requirements. In this survey no in-depth investigations of multitudes of past regulatory locally established requirements were undertaken. Basically, pipe material requirements usually relate to ASTM standards as referenced in plumbing codes; galvanized steel, copper piping and plastics are in accord with standards for such materials. Changes for types of plastic piping materials and variations have occurred over the past four decades. Pipe sizing modifications by 'water supply fixture units' in plumbing code tabulations have recently taken into account changes for water conservation requirements.

4.1 Required Plumbing Codes and Standards.

The BOCA Basic Plumbing Code/1978 (11) required "new or repaired potable water systems shall be disinfected prior to use whenever required by the authority having jurisdiction". Detailed requirements provide descriptions for the water-chlorine solution method that required contact standing period of minimal three hours with flushing until chlorine does not remain (compared relative to local supply) and followed by bacteriological examination specified by local authority. Sample repetition was required if contamination persisted. No other portents for hazards that could impact such systems or other safe water needs were particularized for clearing the piping system and apparently not considered.

The National Standard Plumbing Code – Illustrated, 1983 (12) Section 10.9 provided for "Disinfection of Potable Water System" The provision indication was "New or repaired potable water systems shall be disinfected prior to use whenever required by the Administrative Authority. The water-chlorine maintained mixture required three hours specified and followed by clearance flushing (with implied sampling). Repetition requirement was made if finding of bacteriological contamination (unspecified method) recurred. No other hazardous conditions were considered or noted.

The American Society of Plumbing Engineers (ASPE) Data Book, 1983-1984 (13) similarly sets requirement in "Cleaning and Disinfection of Domestic Water Supply Systems". There, the specification included added information on mechanical and pump arrangements with needs:

- All outlets during chlorine injection be fully opened at least twice during injection and residual checked with orthotolidin solution at not less than 50 parts per million at all outlets before valve closure. Retention in the piping not less than 24 hours; residual after retention not less than five parts per million (if less, repeat process). Clearance by clean potable water until residual chlorine shall not be greater than incoming supply. For hot and cold water lines at least one sample submittal to an approved laboratory. Acceptance requires results that show absence of coliform organisms (acceptable test method for results under local requirements). Repeat needs specifics define repeated testing as necessary.

The Uniform Plumbing Code (2003) Chapter 6 'Water Supply and Distribution' provides for water supply and distribution requirements for water system testing. (14). Materials allowable are set in Section 604 and added specialty usages in Section 609.3[‡] provides for ferrous piping as well as copper tubing requirements. The piping system (609.4) provisions establish working pressures and other related factors. Other

[‡] Maximum velocities established due to cavitations deterioration Section 601.12

sections detail pipe identifications for rapid recognition and also requirements and provisions for details concerning installations and pipe sizing.

Disinfection of Potable Water System in Section 609.9 for new or repaired potable water systems requires "… shall be disinfected prior to use whenever required by the Authority Having Jurisdiction". The method to be followed shall be that prescribed by the Health Authority; in case no method is prescribed the following applies if no prescribed method exists. Necessary provisions call for:

> 609.9.1 - The pipe system shall be flushed with clean, potable water until only potable water appears at the points of outlet. 609.9.2 - The system or parts thereof shall be filled with a water-chlorine solution containing at least fifty (50) parts per million of chlorine, and the system or part thereof shall be valved off and allowed to stand for twenty-four (24) hours; or, the system or part thereof shall be filled with a water-chlorine solution containing at least two hundred (200) parts per million of chlorine and allowed to stand for three (3) hours. 609.9.3 - Following the allowed standing time, the system shall be flushed with clean, potable water until the chlorine residual in the water coming from the system does not exceed the chlorine residual in the flushing water. 609.9.4 - The procedure shall be repeated if it is shown by bacteriological examination made by an approved agency that contamination persists in the system.

The International Plumbing Code, Chapter 6, has comparable provisions.

Apparently no elements of information introduce useful or applicable provision(s) beyond coliform analyses. Consequently, concerns for other hazardous remedial detection purposes and alleviations requires other developments for detecting and eliminating multitudes of hazardous materials (viral-bio-radiological). Emerging literature from on-going research and developments for instrumentation measurements of hazardous materials presence in water mains can become sources for new required guides and codes/standards if unclassified open literature is made available. Materials applicable to newly developed guides and criteria for methods and safety levels can be introduced for required analyses and methods embracing biofilms and linked hazards. Laboratory facility selections appear optional currently for local established requirements; seemingly any facility would suffice for analyses of concern. Other concerns arise for higher levels of dangerous substances analyses in specifications for laboratory types that may have to be at protective level three or four.

4.2 Water Utility Requirements

Utility water system qualities for delivery into building plumbing systems have concerns for foreign materials. The reference American Water Works Association (AWWA) Standard C651-05 (revision of C651-99) 'Disinfecting Water Mains' [15] for potable water supply systems (wells included) provides detailed requirements in systems clearance testing. Provisions indicate required conditions for parameters of concern in procedures and testing results. The scope is for disinfection of new construction and system elements in repairs/maintenance that can cause exposure to contamination. Infectivity sources are not defined or detailed for alerts and necessity for treatment.

Cooperative actions by consortium of interested parties developed the newly revised document; concerns for drinking water additives were relegated to NSF/ANSI 60 “Drinking Water Treatment Chemicals” and NSF/ANSI 61 “Drinking Water System Chemicals”. NSF/ANSI 60 has no provisions for substances not regulated by contaminant levels in US EPA lists for final maximum contaminant level (MAL). Details provide chlorine disinfection, description of the disinfection procedure, preventive and corrective measures during construction, methods of chlorination, final flushing, bacteriological testing, re-disinfection, and final connections to existing mains, disinfection procedures when cutting into or repairing existing mains, and special procedures for caulked tapping sleeves. Details in Appendices indicate descriptive notes on chlorine residual testing, chlorine dosages, and disposal of heavily chlorinated water.

Provisions for applications of additives as liquid chlorine, or solids of sodium hypochlorite or calcium hypochlorite are specific. The end state findings after disinfection of bacteriological quality by a laboratory test are specified. Detailed methods for application of a selected disinfection material are given since modes of applications/usages require differing techniques. Solids require dissolution, need particular placements and times for solutes to form for the intended function. Charts present required flow rates with flushing requirements for various size pipes and hydrant openings to achieve effective system clearance flushing. Constraints on discharges of heavily chlorinated water and potential need for neutralizing outflow during flushing provides for satisfying locally established regulatory controls of such discharges. Other detailed information is provided; e.g., sterile bottles in sampling procedure *(Standard method for Examination of Water and Wastewater),* no presence of coliforms, recording results. Need for added disinfection when failure to achieve clearance specification is established and the requirement for additional treatments until achievement of satisfactory results. No provision(s) for any materials other than coliform are made; determinations if other hazardous materials (viral-bio-radiological) may occur were not established in this conventional consideration.

5. Conclusions and Recommendations

5.1 Consequence

“Uncharacteristic situations” of biofilm concerns have indicated potentials and realistic aspects from fire sprinkler systems investigated deterioration factors. Those imply paradigm potential applications for concerns in damage recovery of varieties of contamination to building water pipe systems with emphasis on formations of attached slimes. Potential hazardous attack efforts that may introduce multitudes of unusual bio-viral-radiological-chemo materials require specific remedial methods for alleviation. A need for establishing response methods based on assured initially rapid detection/measurement methods looms large. Current open literature has not discussed threat recovery techniques for such concerns.

Developing confidence in the basic steps to overcome unusual degradations of potable water quality requires various considerations for isolating, diminishing and eliminating persistence and damaging extension by confirmed prevention methods. Practices and guides for first line defenders in immediacy reactions to hazards, with minimization of damages to water supply systems require intensive undertakings. Initially, potentials from trial studies derived from MIC sources appear as a useful initial step for remediation. Those would establish draft protocols for emergency reactions and practical and useful guides and practices for immediacy needs and follow-on practices. Dislodgement of slime on walls is an important first step in removals of potential lodgment sites for deleterious contaminants' conditions in building water supply systems. Concerns in restoration must include considerations require pipe materials differences considerations; differing techniques are likely needs for copper, galvanized and plastic water supply piping.

5.2 Research Recommendations

Flushing building plumbing potable water supply systems field tests is required by quantifying water necessary for total flushing (soluble materials or wall attached/removable materials). Determinations are important in events that preclude water mains supply and require stored water tank truck volumes. Potentially hazardous materials in flush water may preclude discharge into waste drain sewers. Assessment and determination of methods for collection/treatment and retention of discharges must also be considered. Potential for reverse osmosis separation of hazardous materials and consolidation of residuals in waste outflow for separation in order to nullify hazardous state(s) needs to be addressed.

Determinations of methods specific to different pipe wall materials in restoration actions need to identify capabilities for withstand of treatment recovery techniques. Investigations are required for utilization of excessive chlorine based additives, or utilization of ultra-violet radiation, or materials impacts from abrasive scouring of pipe walls in order to prevent deleterious materials impacts and induce integrity failures. Investigations related to induced destructive impacts requires attention.

Fundamentals of understanding wall attached growths or adhesion parameters by many deleterious foreign materials (and elimination thereof) need to be examined. Exposure conditions evaluations are required for the susceptibility of all elements that comprise piped building systems, controls/fixtures, appliances and hot water tanks, and water heaters needs to be evaluated. Recovery practices, or simply need for replacement decisions, require study so that response guides provisions (for local published municipal information/procedures) can be prepared for applications by first line responders and local officials.

Fundamental investigations are required on mixtures of flows with solutes and particles or contaminants. Governing laws on wall deposition growths, chemo-kinetics and dynamic time dependencies for chemo-bio rate equations of substances and materials in the water flow need to be determined. Radial dependencies on diffusion rates must be applied since cylindrical coordinate areas in flow actualities vary inversely with radial distances. Consequently, transport phenomena of species in the flow have altered concentrations of chemical materials and bio-species (peripheral areas increase linearly toward wall surfaces) and govern reaction kinetics and diffusion/transport to/from wall surfaces. Surface tension relations to wall attachment mechanisms and understanding adhesion or release of materials must be developed. Adaptations of computer methods (commercially available methods from aero-space rocket combustion investigations) can apply but require species and mixtures of constituents for these concerns.

Analyses of attachment and release processes at pipe wall surfaces, and/or substrates, requires input from dynamic reaction kinetics with formulations for chemical-bio-flow processes. Examination of details of material compounds at, and within, wall cavities or porous substrates in flows and sub layers on wall locations are necessary. Impacts from introduction of materials, such as surfactants and biocides, which result in foreign materials interactions, require experimental research and advancing applications from fundamentals of theory. Experimental evaluations for many type materials to establish neutralization, removal or extracting hazardous substances must be undertaken.

5.3 Conclusions

Applicable problem sectors were reviewed that relate issues concerning quality assurance of potable water supply in buildings and/or reducing impacts from disruption of water potable qualities. Most aspects of concern were significance of understanding of detection and determinations for compositions/constituents of biofilms and attachment mechanisms/formations that impact on the integrity the piping materials or potentials for water contamination.

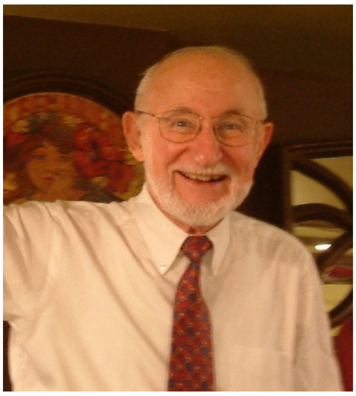
Microbial Induced Corrosion (MIC) in wet fire sprinkler systems provided the greatest sources of information and remedial commercial practices for elimination of intrusive films on piping materials. Potable water protection and testing from plumbing codes and standards were inapplicable to specifics and analyses beyond coliform determinations. Water utility supply pipe clearance requirements did not extend plumbing practices but offered more details.

Paramount need for methods of recovery by elimination of deposits in the pipe system from terror type contaminants or naturally occurring biofilms may be advanced from comparable investigative results. Techniques applied for detection and elimination of MIC system degradation sources and deterioration of potable water quality has potentials for extension. Indicated methods for systems renovation may be applicable to building potable water piping restorations and other benefits from research already undertaken.

6. References

1. 'Center for Biofilm Engineering' Bozeman Biofilm National Center, United States Information, Montana State University, Boseman, Montana
2. Correc, O., Derrien, F., Diab, Y., An Original Tool to Investigate Drinking Water Distribution System, CIB W62 Water Supply and Drainage for Buildings Symposium Sept. 14-16, 2005 Brussels, Belgium
3. National Association for Fire Prevention NFPA, Series 13 Standards (various dates)
4. State of Maryland Final report: Task Force to Study pinhole Leaks in Copper Piping, Dec. 2004, Annapolis, MD
5. Practical Guide to Diagnosis & Mitigation of Microbiologically Influenced Corrosion (MIC) in Fire Protection Systems. BTI, 2005
6. Denver airport corrections
7. Dowling, N. J., Mittelman, m. W., Danke, C. D., Editors, Conference Proceedings on Microbially Induced Corrosion and Deterioration, The University of Tennessee, Knoxville, GA., October 7-12. 1990
8. Chamberlain, A. H., L., Angell, P., Influences of Microorganisms on Pitting of Copper Tube (see {13}, pp 3-65-71)
9. Wagner, P. A., Little, B.J., Microbiologically Influenced Corrosion in the presence of a Copper Tolerant Bacterium, (see{13} pp8-13-15)
10. Fischer, W., Paradies, H. H., Hänssel, Copper Deterioration a Water Distribution System of a County Hospital in Germany Caused by Microbial Induced Corrosion, (see {13}, pp 8-47-48)
11. ASPE Data Book 1983-84, Volume 1Fundamntals of Plumbing Design, American Society of Plumbing Engineers, Sherman Oaks, CA. (currently - Chicago, IL)
12. Uniform Plumbing Code, IASPMO/ANSI UPC 1-2003,International Association of Plumbing, and Mechanical Officials, Ontario, CA
13. BOCA BASIC PLUMBING CODE 1978, Fourth Edition, Building officials and Code Administrators International, Inc., Chicago, IL
14. National Standard Plumbing Code, Illustrated, National Association of plumbing-Heating Cooling Contractors, Washington, D.C.
15. IAPMO/ANSI UPC 1-2003 Uniform plumbing Code, Twenty-Third Edition, Seventh printing Nov. 2005, Philadelphia Street, Ontario, CA
16. AWWAC651-05 Disinfecting Water Mains American Water Works Association, 01-Jun-2005 36 pages

6. Author



Dr. Lawrence Galowin, consultant, experienced at National Institute of Standards and Technology (NIST) as leader in plumbing research. He is now a Guest Researcher. Consultant - desalination developments based on wave energy pumping for RO methods; potable water relief to worldwide sites by Slow Sand Filtering - performance parameters research.