Tech Brief

PUBLISHED BY THE NATIONAL ENVIRONMENTAL SERVICES CENTER

Biofilm Control in Distribution Systems

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Summary

A biofilm is a surface deposit of bacteria, other microorganisms, and organic and inorganic materials that accumulate within a slime layer. Biofilms can form on solid and liquid surfaces when nutrients and water are present. Much like the plaque that forms on teeth, biofilms also form inside drinking water distribution systems and can sometimes cause a number of problems.

Biofilm Formation

Distribution systems, even in small systems, are complex environments that can provide many opportunities for biofilm development. This development may occur fairly rapidly or slowly, sometimes over a period of years. However, clean pipes, especially metal pipes, are not initially attractive surfaces for bacteria.

Bacteria are typically the first microorganisms to colonize pipe surfaces. Once enough organic material adheres to the pipe surface—a process referred to as "conditioning"—bacteria can begin to attach. Once the bacteria reach a critical density, they begin to produce a gelatinous substance that gives biofilms their characteristic slimy nature. This slime layer makes up the majority of the weight and volume of the biofilm.

After the slime layer forms, a veritable micro-ecology can flourish. The slime layer helps trap additional organic particles that many bacteria can use for food and energy. Other microorganisms including viruses, protozoa, algae, fungi, and helminthes may become associated with or entrained within the biofilm. Some protozoa graze on biofilm bacteria creating a food web.

Biofilms provide a number of advantages for attached organisms compared to free-floating (planktonic) organisms. In a low-nutrient environment, it is easier for microbes to let the nutrients come to them rather than to search for the nutrients. The slime layer allows metabolic by-products or wastes to accumulate, some of which may be used as food by other microorganisms, forming a cooperative ecology. The biofilm also protects the inhabitants from the effects of disinfectants—biofilm microbes are many times more resistant to disinfection than planktonic microbes.

Biofilms can often be seen accumulating in household dehumidifiers.

Biofilm thickness is variable but is usually in the range of 50 to 100 microns. As the thickness increases, pieces of biofilms can shear off, allowing for colonization of downstream sections of the system.

How do microorganisms get in the system?

Microorganisms can enter the distribution through two main categories: (1) surviving the treatment process and (2) recontamination. Most microorganisms found in distribution systems biofilms are also found in the system's source water. They may survive due to ineffective treatment such as filter breakthrough or ineffective primary disinfection. However, even effectively treated water contains some bacteria in small numbers. Potable water is not sterile.

Assuming water of good quality enters the distribution system, there are still numerous ways the water can be contaminated, including cross connections and back flow. Leaking pipes, joints, and valves can also allow for the entry of microbes, especially during temporary periods of negative pressure.

Poorly designed or maintained finished water reservoirs and tanks can allow for recontamination if birds and other animals, including humans, have access. Because sediment can accumulate in tanks and reservoirs, providing a habitat for microorganisms, storage units can be a major focus of recontamination problems, especially in tanks where the water has long residence times.

Repairing and replacing distribution system components also allows for the introduction of microorganisms if care is not taken to disinfect repaired or replaced mains and tools introduced into the system, such as mobile cameras.

Problems Associated with Biofilms

Just as all teeth have some plaque, all distributions harbor some biofilm. In both cases, problems can occur when they are not controlled. Public health concerns related to distribution system biofilms include the documented presence of primary and opportunistic bacteria, viruses, protozoa, and fungi. Although primary pathogens (those that can cause disease in healthy people) have been detected in biofilms, there is little information on waterborne disease outbreaks conclusively linked to biofilms.

Perhaps of greater concern is the persistence of opportunistic pathogens in biofilms. Oppor-tunistic pathogens are those that cause disease in people with weakened immune systems such as AIDS patients, diabetics, organ transplant recipients, and many cancer patients, as well as other susceptible groups such as the elderly and young children. These populations easily number in the tens of millions nationally. Opportunistic pathogens include *Pseudomonas aeruginosa*, *Legionella pneumophila*, and the *Mycobacterium avium* complex (MAC).

In addition to public health concerns, biofilms can contribute to taste, odor, and color problems. They can also mask coliform occurrences since biofilm bacteria can compete with and suppress coliform growth on solid media. (This is much less of a problem with liquid-media-based presence/absence tests.)

Because coliforms, once established, can reproduce within biofilms, positive coliform tests may occur even though the water entering the distribution systems may be coliform-free. Even though these regrowth coliforms are not of fecal origin, they can still result in rule violations and headaches for operators.

Some biofilm organisms can also accelerate the corrosion of some types of pipes. Iron-oxidizing bacteria oxidize iron and steel, depositing iron oxides (rust) in raised deposits called tubercles. Sulfur-oxidizing and sulfur-reducing bacteria produce sulfuric acid and hydrogen sulfide, respectively, which can cause pitting of pipe surfaces. Corrosion products, such as iron oxide sediments and tubercles, provide additional habitats and attachment sites for other biofilm organisms.

Factors Influencing Biofilm Growth

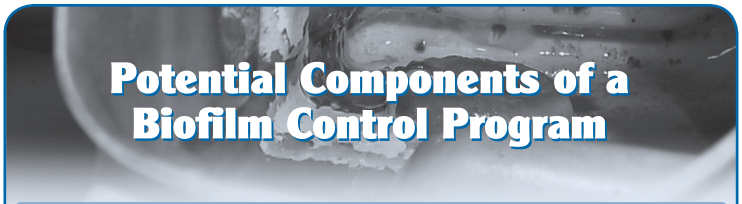
Distribution systems are complicated environments in which a number of different factors interrelate resulting in no two systems being exactly the same. Several factors influence biofilm growth, usually in combination, with no single factor dominating in all cases.

One of the most important factors determining the extent of biofilm growth is the presence and concentration of nutrients. Carbon, nitrogen, and phosphorus are needed for the growth of heterotrophic bacteria. Proportionally, more carbon is required, so carbon is usually the growth-limiting element. The source of most carbon is natural compounds from living and decomposing vegetation. These organic compounds are more associated with surface water sources and groundwater under the direct influence of surface water. These compounds are also the precursors of disinfection by-products.

Because simpler forms of organic carbon are more easily consumed by microbes, the type, and the concentration of organic carbon affects the potential growth of biofilm. Several methods for measuring the potential of waters to stimulate biofilm growth have been developed. By limiting the concentration of organic carbon available to microbes, many European water systems are able to control biofilm growth in distribution systems with relatively low concentrations of disinfectant residual. In fact, some European systems use no residual disinfectant.

Biofilm growth is often associated with warmer temperatures and can be seasonal in nature. This factor is complicated, however, by the decreased efficiency of disinfectants and the longer survival times of most fecal bacteria at lower temperatures. In some systems, rainfall events have also been associated with increased biofilm growth, due to higher concentrations of nutrients, turbidity, and bacteria in the source water, leading to treatment breakthrough.

Some types of distribution systems materials are more prone to biofilm development. Biofilm develops more rapidly, more densely, and is more diverse on iron pipe, especially older pipes, compared to PVC pipes. Other com-



Potential Components of a Biofilm Control Program

Source Water Protection

Monitoring and Maintenance of Adequate Plant Performance
- monitor individual filter effluents as well as plant effluent

Reduce Organic Carbon/ Nutrient Levels
- coagulation
- precipitative softening
- activated carbon filters
- mixed carbon/sand filters
- biologically activated filters

Corrosion Control
- use chemical inhibitors
- adjust pH

Reservoir Maintenance
- rinse prior to use
- limit retention times
- maintain adequate residuals
- monitor sediment accumulation
- keep covered and secure

Appropriate Disinfection Practices
- increase free chlorine residual
- use alternate disinfectant

Distribution System Maintenance
- regular flushing
- eliminating cross-connections
- modifying dead ends
- line pigging
- pipe replacement

Personnel Training

Source: Modified from U.S. EPA

ponents can also support biofilm growth including materials used in valves, gaskets, washers, pump lubricants, and pipe coatings. Some European countries test all system components for biofilm growth potential to determine their suitability for use in distribution systems.

The hydraulics of a system are another important and complicated factor. Long residence times due to dead ends and low flow rates are associated with loss of disinfectant residual and high levels of biofilm growth. Multiple variables such as velocity, pressure, overall system configuration (looped or branching), pipe sizes, and maintenance practices, such as regular flushing, affect biofilm development.

The type and concentration of disinfectant used can affect biofilm growth. Chlorine residual is consumed by biofilms and does not penetrate thick biofilms very well. Monochloramine is less reactive and penetrates better. Systems using monochloramine for residual disinfection tend to have fewer coliform-positive tests. Both disinfectants have benefits and drawbacks, so changes in disinfectants must be carefully considered. The point of disinfection can also be critical. Some systems applying chlorine or ozone just prior to the distribution system have experienced increased growth in biofilms. This occurs when complex organic carbon molecules such as humic or fulvic acids, which are hard for bacteria to consume, are oxidized by the disinfectant into smaller molecules that are more easily assimilated.

Corrosion, even when it is not biologically mediated, can affect biofilm growth. Pits and tubercles act as traps for nutrients and attachment sites for microbes. Iron oxide corrosion products may act as a microbial nutrient and protect microbes from chlorine disinfection.

Detecting and Controlling Biofilms

Biofilm overgrowth can be indicated by the presence of coliforms in distribution system samples when the treatment plant effluent is coliform negative. Other indications are high densities of coliforms in the distribution system when contamination due to cross connections and back flow has been ruled out. Other possible indications include the rapid loss of disinfectant residual, increases in the concentration of heterotrophic bacteria (those that require organic carbon) as measured by Heterotrophic Plate Counts (HPC) and the assessment of easily biodegradable carbon levels, as measured by laboratory tests such as Assimilable Organic Carbon (AOC).

A number of test kits are commercially available that quantify the amount of active microbial biomass by measuring the presence of adenosine triphosphate (ATP). ATP is a molecule found in all living cells that plays a key role in energy transfer and metabolism. These kits extract ATP from microbial cells, convert it to light, and measure the light emitted in a hand-held luminometer. They have the advantage of providing results in minutes rather than days.

Because so many factors can influence biofilm growth, there are numerous ways to prevent and control biofilm growth. A successful program will incorporate multiple approaches. A distribution system maintenance program may include regular line flushing, which helps redistribute residual disinfectant to all sections of the system and removes existing biofilms and sediments. Lines with severe corrosion tubercles may require line pigging. Neither flushing nor pigging is a permanent solution and neither may be enough to control well-established biofilms. In some cases line replacement may make more sense. New line materials should be washed to remove surface contaminants and disinfected when possible.

Maintaining an adequate level of residual disinfectant has long been the primary way to maintain water quality in distribution systems. Chlorine has the advantages of being relatively simple and economical. However, when dealing with established biofilms, it has some disadvantages. As mentioned, chlorine does not penetrate thick biofilms and sediments very well and is consumed by side reactions with organic material. Monochloramine is more effective at controlling biofilm growth, but has other disadvantages including toxicity to humans and fish, which limits its maximum concentration. Monochloramine is also less effective than chlorine for controlling unattached, free-floating organisms. While secondary disinfection can be a key component of a biofilm control component, it should not be the only one and disinfection strategies need to be well planned.

For systems where biofilm growth is attributed to high levels of nutrients, additional in-plant treatment to reduce organic carbon levels may be beneficial. This potentially has advantages besides decreasing biofilm growth, including decreasing the amount of chlorine residual consumed in side reactions with organic material and decreasing the amount of disinfection by-products. There are many methods to reduce organic carbon, including the use of activated carbon filters, and slow and rapid sand filters. Some methods are in part biological processes. In these, microbial activity is enhanced prior to distribution to limit it during distribution.

Corrosion control can also help control biofilm growth by reducing or eliminating attachment sites for microorganisms. Methods of corrosion control include chemically modifying the water to make it less corrosive (pH adjustment), applying corrosion-resistant linings or coatings, and using corrosion inhibitors such as phosphate-based inhibitors. Because chlorine can react with iron pipes, corrosion control methods also help to maintain residual chlorine concentrations and improve biofilm disinfection.

Reservoirs can present special challenges and require regular maintenance to prevent regrowth problems. Maintenance procedures include cleaning tanks prior to being put into service, limiting residence time, maintaining disinfectant residuals, preventing access by animals, and regular monitoring.

A successful biofilm control program can include all aspects of a water system, including a source water protection plan. A multiple approach strategy is more likely to control established biofilms as well as prevent future occurrences.

For more information:

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Published by The National Environmental Services Center at West Virginia University, P.O. Box 6064, Morgantown, WV 26506-6064