Biofilms and Nitrification

Vanessa Speight
TWG Representative
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This Meeting's Presentations

Objectives

Provisions

System compliance

Improvement

Research

Biofilms and Nitrification Research and Information Collection Needs

Presentation Objectives

- Define the distribution system issue
- Explain why this topic is of concern and may warrant additional research / information collection
- Review the current state of research
- Describe decision-relevant research and information needs
- Identify linkages to related topics and cross-cutting issues

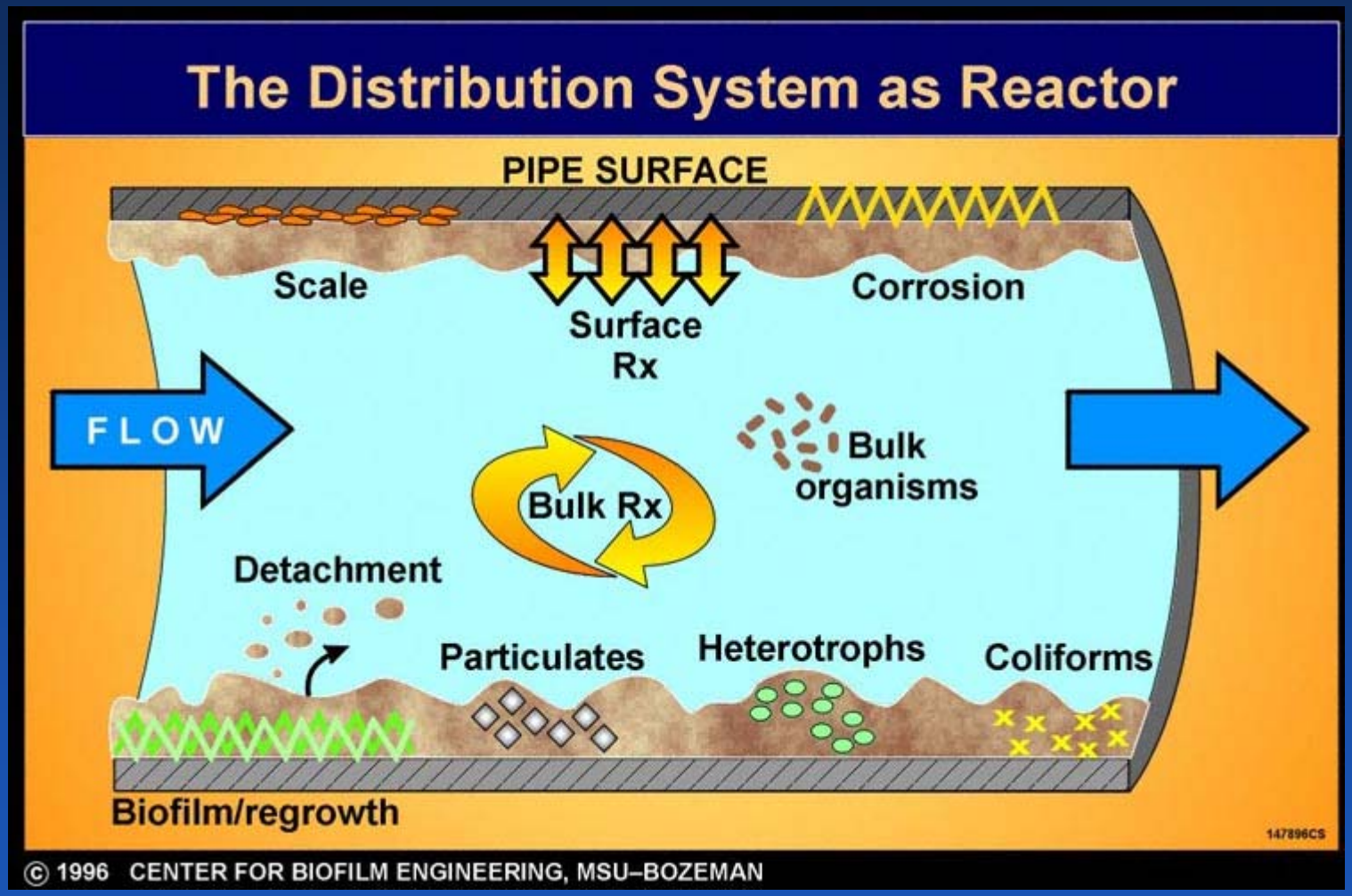
Biofilms and Microbial Regrowth

Definition: Biofilms and Microbial Regrowth

- A biofilm is a mixture of microorganisms, inorganic and organic matter that adheres to a surface such as a pipe wall
- All materials in contact with drinking water have some level of biofilm since water is not sterile
- Biofilms and/or organisms can detach from the pipe wall and enter the water for a variety of reasons:
  - During increased flows related to fire fighting or main breaks
  - Due to reversal of normal flow direction in pipes
  - In response to a change in water quality

Definition Continued

- Biofilms can:
  - Exist as continuous or patchy films along interior surfaces of distribution system materials
  - Trap organic and inorganic chemicals as well as microorganisms from the water
  - Act as a slow-release mechanism for continual seeding of the water with biofilm matter
  - Be resistant to disinfection
  - Provide a growth medium for bacteria, algae, fungi and protozoa
  - Shelter pathogens
  - Enhance or potentially reduce corrosion of DS materials, and associated metal release
  - Impact the release of contaminants that have accumulated in the DS
  - Accelerate disinfectant decay



Source: Anne Camper / Peg Dirckx, CBE

Magnitude of Public Health Concern

- Biofilm can be inhabited by pathogens
  - Biofilm may provide opportunity for pathogens to accumulate and subsequently be released
- The magnitude of public health concern can range from zero to community-wide outbreaks
  - Duration of *Campylobacter* exposure and illness thought to be extended due to secondary reservoir in biofilm (one study in Sweden)
  - *Legionella* is the most commonly identified waterborne pathogen by CDC and is associated with hot water systems, cooling towers and biofilm in premise plumbing

Mitigation Strategies: Regulations

- Some microorganisms that are associated with biofilms have been added to CCL-2:
  - Mycobacterium avium complex (MAC) and *H. pylori*
- Regulations on monitoring total *Legionella* in aerosols released from cooling towers (not part of SDWA)
- Guidance exists on biofilm management practices

Mitigation Strategies: System Practices

- Limit nutrients entering the distribution system (organic carbon, nitrogen, phosphorus)
- Control system hydraulics to:
  - Minimize low flow areas
  - Reduce residence time, turn over storage
  - Maintain consistent flow rates and direction to prevent sloughing
- Conduct periodic flushing in the areas susceptible to biofilms
- Employ appropriate corrosion control practices for distribution system materials and water quality
- Reduce microbial entry into the distribution system by addressing treatment effectiveness and physical system integrity
- Maintain disinfectant residual

Implications for Different Systems

- Some NCWS only have premise plumbing and thus biofilm issues would be related to premise plumbing
- The capacity of individual systems to address and control biofilm will vary depending on source water quality, use of disinfectant residual, extent of distribution system and the resources to implement controls

State of the Research

- There exists a very basic understanding of microbial ecology in the distribution system
- Some mathematical models have been developed, most include only single microbial population dynamics and are difficult to generalize
- Preliminary understanding of the impacts of different disinfectants and other water quality parameters on biofilm growth has been developed
- Preliminary understanding of the linkage between microbial growth and corrosion has been developed
- Findings of pathogens in biofilms continue to emerge
- Good understanding that coliform bacteria and E coli can exist in biofilm

State of the Research – Health Effects

- Very difficult to quantify health risk
  - Lack of in-situ measurement capabilities
    - Generally rely on samples from bulk water or coupons to quantify biofilm
  - Potential indicators of biofilm (TC, EC or HPC) do not necessarily correlate to pathogen occurrence
  - Variability in events that lead to biofilm sloughing
    - Hydraulic changes (e.g., flow reversal or surges)
    - Water quality changes (e.g., loss of residual)
  - Differentiating between health risk from distribution system biofilm vs premise plumbing biofilm is difficult

Research / Information Gaps for Biofilms	Exposure / Vulnerability	Health Effect / Risk	Mitigation Strategy
Develop analytical framework for assessing biofilm occurrence & exposure	++ (1-5 y)		
Understanding of the sources, fate and transport of pathogenic and non-pathogenic organisms in biofilms	++++ (5-10 y)	+++++ (>10 y)	
Factors that promote biofilm growth that could lead to public health risk		++++ (5-10 y)	
Characterization and detection of events leading to biofilm release	++++ (5-10 y)		
National characterization of pathogens related to biofilms	++++ (1-5 y)		
Determine effectiveness of different control measures and secondary impacts			++++ (5-10 y)

Nitrification

Definition: Nitrification

- Microbiological process by which ammonia is first oxidized to nitrite and then to nitrate
- Primarily caused by two groups of naturally-occurring bacteria
  - Ammonia-oxidizing bacteria (AOB): oxidize ammonia to nitrite
  - Nitrite-oxidizing bacteria (NOB): oxidize nitrite to nitrate
- Nitrifying bacteria growth rates are controlled by factors such as: substrate concentration, temperature, pH, light, oxygen concentration, microbial community composition, and possibly phosphorus
- Ammonia found naturally in some source waters or added during formation of chloramine

Magnitude of Public Health Concern

- Nitrification produces nitrite and nitrate, which are regulated contaminants
  - Currently regulated at entry point to distribution system only
  - Nitrite formation during distribution system nitrification can exceed 1 mg/L entry point MCL
- Nitrification causes deterioration of water quality because it leads to:
  - Disinfectant residual decay
  - Proliferation of bacteria (as a result of disinfectant decay), possibly pathogens
- Nitrification can result in further deterioration of water quality:
  - Reduction in pH can lead to corrosion and metal release
  - Consumption of oxygen which can lead to metal release and other issues
  - Reduction in alkalinity
  - Production of taste and odor compounds
- Nitrification can also be related to biofilms

Mitigation Strategies: Regulations and Guidance

- Both nitrite and nitrate are regulated drinking water contaminants at the entry point to the distribution system
  - Nitrite MCL = 1 mg/L
  - Nitrate MCL = 10 mg/L
  - With increased monitoring when ½ of the MCL is detected
- Regulated minimum chloramine residual concentrations can be difficult to maintain during a nitrification episode, which can lead to coliform rule violations
- Some states require chloraminated systems to prepare nitrification control plans
- Guidance: AWWA M56, Fundamentals and Control of Nitrification in Chloraminated Drinking Water Distribution Systems

Mitigation Strategies: System Practices

- Disinfection practices:
  - Maintaining an appropriate chloramine residual
  - Management of chlorine to ammonia ratio to minimize the free ammonia concentration

- Monitoring for indicators as part of a nitrification control plan:
  - Loss in chloramine residual
  - Increase in nitrite and nitrate
  - Changes in free ammonia concentration
  - Drop in pH, alkalinity or dissolved oxygen
  - Increase in HPC concentration

Mitigation Strategies: System Practices Continued

- Minimize chloramine decay in treated water
  - Removal of TOC and inorganics during treatment

- Optimize distribution system operations and maintenance practices
  - Minimize water age, especially for storage
  - Control corrosion by appropriate water chemistry manipulations
  - Scheduled flushing

- Distribution system engineering improvements
  - Reconfigure inlet/outlet of storage facilities to minimize water age
  - Application of mechanical mixers to reduce stagnant zones
  - Elimination of dead ends
  - Chloramine boosting
  - Remove (oxidize) natural ammonia by biological filtration
  - Chlorite has shown promise in some situations

State of the Research

- Field testing methods for by-products of nitrification are well developed
  - Portable tests for free ammonia, nitrite, nitrate are readily available
- Limited ability to directly measure nitrifying organisms
- Preliminary understanding of the microbial processes associated with nitrification
- Good understanding of the primary water quality impacts caused by nitrification (e.g., residual decay)
- Preliminary understanding of the simultaneous water quality impacts (e.g. corrosion) associated with nitrification
- Preliminary understanding of some of the mitigation measures for preventing nitrification
- Preliminary understanding of the mitigation measures for responding to nitrification once it occurs

Research / Information Gaps for Nitrification	Exposure / Vulnerability	Health Effect / Risk	Mitigation Strategy
Advance understanding of nitrification process to determine growth /inactivation parameters, develop water quality models, etc.	+++ (1-5 y)		
Develop rapid, simple methods for measuring nitrifying organisms	+++ (5-10 y)		
Develop an understanding of mechanisms of corrosion caused by nitrifying organisms and relationship to different corrosion control strategies	+++ (1-5 y)		
Link between secondary impacts of nitrification in distribution systems and public health impacts		++++ (5-10 y)	
Determine effectiveness of different prevention and control measures, including unintended consequences of other issues (e.g., DBPs, corrosion)	+++ (1-5 y)		+++ (5-10 y)

Research / Information Needs for Nitrification Continued	Exposure / Vulnerability	Health Effect / Risk	Mitigation Strategy
Develop national estimate of occurrence of nitrification, including prevention/control methods, distribution of nitrifying organism species and regional differences	+++++ (1-5 y)		+++++ (1-5 y)
Delineate between source water and chloramine sources of ammonia for nitrification	++++ (1-5 y)		
Develop national estimate of exposure to nitrite and nitrate in distributed water	+++++ (1-5 y)		

Cross-Cutting Issues

- Nitrification can also be a biofilm process
- Any mechanism for microorganisms to enter the distribution system can lead to increased biofilm
  - Treatment
  - Physical breach
  - Cross-connection
- Adverse impact on water quality parameters due to nitrification and biofilm can affect:
  - Physical system integrity (e.g. corrosion)
  - Disinfectant residual available to inactivate pathogens
  - LCR compliance
  - Potential for release of regulated metals into drinking water
- Water age, internal corrosion, disinfectant residual loss, storage facility operations all relate to nitrification and biofilm to some degree
- More systems switching to use of chloramine