Potable Water Treatment: Biofilms in Water Distribution

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ABSTRACT

Among the numerous types and groups of bacteria that had been identified in distribution systems, 'Psedomonas', 'Flavobacterium', 'Aeromonas', 'Acinetobacter', 'Corynebacterium', are frequently mentioned (Block, 1992; Bourbigot et al. 1984; Maki et al. 1986; Nortan and LeChevallier, 2000; Payemnt et al. 1988,1994; Power and Nagy, 1999; Ribas et al. 2000; van der Kooij, 1977). The fairly irregularly dispersed accumulation of aggregates of microorganisms on materials consisting of organic polymers and extracellular polysaccharides (EPS) can be termed as drinking water biofilm. The environmental factors, hydraulic effects, nutrient availability (carbon, nitrogen and phosphorus), other sources of nutrients, disinfection residual concentrations, corrosion and sediment accumulation are the factors that favor the biofilm growth. The types of coliform bacteria found in distribution system biofilms may vary according to location and the procedures used to analyze samples, but the predominant coliform species (ssp.) generally include Enterobacter cloacae, Klebsiella spp, Citrobacter freundii, and Enterobacter agglomerans (Geldreich, 1986). The present emphasizes these factors, which favor the biofilm growth and its occurrence and also the biofilm control strategies through distribution system monitoring (DMS), which can be detected by the breakthrough contamination, examination of pipe surfaces and hydrodynamics along with the measurement of nutrient levels. For the analysis of the biofilm control strategies, the biofilm control plan comprising of comprehensive maintenance program, maintenance of reservoirs, corrosion control and controlling nutrient levels has been studied.

KEYWORDS

Distributed System Monitoring (DMS), Extracellulose polysaccharides (EPS), Coliform Bacterium (E.Coli), Disinfection Residual Concentrations, Corrosion, Nutrients.

INTRODUCTION

Drinking water distribution systems have an intake of suspended bacteria from different sources such as the bacteria present in groundwater and raw surface waters which is not removed even after the treatment, the bacteria yielding from the treatment processes such as biofilters and/or bacteria which is introduced by water which is obstructed from other aquatic environments. Most of these bacteria are autochthonous and hence are able to grow in the interior of the distribution system in the water phase and on the surface of distribution pipes where they can be abraded by the flow of propagating water. The growth of microorganisms in drinking water systems is not new. The American Water Works Association (AWWA) reported the presence of "B Coli" bacteria and they have found the reoccurring growth of it in the drinking water systems. Even though there is no bacterial growth or presence in the point of supply but at the point of distribution pipeline their presence is evident, this gives a clear indication that they are being produced inside the distribution pipelines. The pictures of these supply pipelines using scanning electron microscope showed the presence of these microorganisms' communities on the pipe surfaces and pipe tubercles.

Even though the microorganisms do not survive during the bacterial treatment at the point of entry, once after their entry into the pipelines they adapt themselves to that environment and start producing communities. Even though through water treatment most of the bacteria can be killed, at the end point there will be some trace of bacteria. This means that water can never be sterile. These biofilms are present in almost all of the distribution systems which are now being categorized under normal aquatic systems. Then again, in all distribution systems similar type of communities do not exist.

Their count varies depending upon the type of treatment and physiochemical parameters, the physical roughness of the surface, and the chemical and thermodynamic properties of the interface. Usually these biofilms harbor the Coli form organisms, which are usually of fecal origin and they violate the Total Coliform rule which states that the presence of this coli form to an extent is not harmful and doesn't have any health risk on consumption. Knowing the type of organisms growing in the distribution systems they can be prevented and safe drinking water can be supplied.

DESCRIPTION

What is a Biofilm?

Biofilms are nothing but the microorganisms which get attached to the pipe surfaces in the distribution pipelines and these microorganisms multiply to form a slime layer. Within seconds these microorganisms along with some macro particles get adhered to the fresh pipe surfaces. These microorganisms get attached o the pipe surface through the adjunct formed from their cell membranes. Apart from this some bacteria get attached to the pipe lines because of a capsular material of extra cellulose polysaccharides (EPS) also called glycocalyx. With the help of these macro molecules the microorganisms not only utilize the nutrients but are also protected.

Biofilms are dynamic microenvironments, encompassing processes such as metabolism, growth, and product formation, and finally detachment, erosion, or "sloughing" of the biofilm from the surface (Characklis, 1981; Safe Drinking Water Committee, 1982; Characklis and Marshall, 1990). Biofilms which comprise of the microorganisms colonies tend to multiply in a nutrient rich environment. This favorable environment is created by the macromolecules which accumulate at the solid-liquid interface, which otherwise would have been a nutrient-deficient situation. Even if the nutrient content in the water is low, due to the high flow rate in the system this can transport tremendous quantities of nutrients to the adhered microorganisms.

The EPS production helps in the adhering of the bacteria to the surface of the pipeline, and this EPS can also be a factor in their nourishment. From this information the microbiologists have concluded that the microorganisms can exist in a solid-liquid interface as long as the nutrients are available.

What kind of Microorganisms make up the Biofilm?

By knowing the type of microorganisms that can persist, and analyzing their growth requirements will enable us to control them or prevent them to establish themselves in the pipelines. To detect these microorganisms in the pipelines, the in situ experiments are not feasible but these can be studies by the samples which are obtained either by scraping of biofilms from the pipelines walls or from their growth on the pipe coupons.

From these samples the variations of the microorganisms and the count of these along with their types can be studied. Although most of these microorganisms are not very harmful, some of them are a threat to the average consumer. From this analysis the main aspect which we have to lay emphasis on is that no matter which kind of treatment is adopted we can never supply sterile water, because of which the microorganisms which are present in the water may cause infections in infants/and or other with weakened resistance. These infection causing organisms are called as "opportunistic pathogens".

Bacteria

Biofilm usually and most commonly comprises of bacteria which can form the major portion of the biofilm population. Heterotrophic bacteria (those requiring organic compounds as sources of carbon and energy) are often measured by the Heterotrophic Plate Count (HPC).

This heterotrophic bacterium is the most commonly found bacteria and the source from which this is evolved is not known. Usually during the disinfection process these bacteria survive and later colonize in the distribution pipelines, or they could be induced through cross connections, backflow (Geldreich, 1990a), although a study by Payment et al. (1991) describes a correlation between heterotrophic bacteria growing in home water filtration devices and gastrointestinal illness.

A group of bacteria which are closely associated with the heterotrophic bacteria are the total coliforms. These coliforms are usually present in the fecal matter of human and/or animals but they can also grow in water, soil and vegetation, which do not comprise of fecal matter.

The main reason for using the coliforms as primary microbial indicator of drinking water quality is the fact that even though they do not have an adverse affect they are usually present along with the enteric pathogens. The types of coliform bacteria found in distribution system biofilm may vary according to location Enterobacter cloacae, Klebsiella spp, Citrobacter freundii, and Enterobacter agglomerans (Geldreich, 1986). E. coli, most often used as an indicator of fecal contamination, has been found in distribution system biofilms, but only rarely (Olson, 1982; LeChevallier et al, 1990a). More often, when E. coli is found it is evident of recent fecal contamination (Geldreich, 1986).

Along with bacteria the other microorganisms that make up the biofilm are the opportunistic pathogens (includes some species of mycobacterium, pseudomonas aeruginosa, legionella spp, aeromonas spp, flavobacterium spp, and some species of klebsiella and serratia), antibiotic-resistant bacteria, disinfectant-resistant bacteria, pigmented bacteria and actinomycetes (which include actinomyces, streptomyces, norcardia, and arthrobacter), fungi (which includes molds and yeasts), protozoa and other invertebrates (which include amoebae, nematodes, amphipods, copepods, and fly larvae)Levy, 1985)).

Factors that favor Biofilm growth

Researchers have investigated through years to determine the factors which are favorable in the growth of biofilm. An increase in the temperature of the water along with the dissipation residuals accompanied by the accumulation of sediments and organic materials in the distribution pipeline systems leads to the growth. Environmental factors (e.g., pH, temperature, and rainfall); nutrient availability; the presence and effectiveness of disinfectant residuals; internal corrosion and sediment accumulation; and hydraulic effects have been related to growth to coliform bacteria in drinking water (LeChevalier et al., 1990a; Smith et al., 1990).

These results give an idea about the susceptibility of the system to biofilm growth and enable us to manipulate the environmental variations for controlling the bacterial growth in the system.

Environmental Factors

The most important factor which regulates the growth of the microorganisms is the presence of the water in the distribution systems. It is considered to be prominent in rate controlling. The efficiency of the treatment plant, the growth rate of the microorganisms, efficiency of disinfection, loss of residuals, rate of corrosion, velocity of water through customer demand, and the hydraulics of the distribution pipeline system are influenced by the temperature.
A drastic effect on the lag time and cell yield has been observed by the variations in water temperature. Another important factor which influences the microbial growth is rainfall. High turbid waters are usually prone to favor the growth of microbes against disinfection.

Hydraulic Effects

The microbial growth on the surface of the pipes may be regulated by the velocity of flow in the distribution systems. An increase in the velocity tends to increase the flux of nutrients in the system there by transporting large amounts of disinfection and, which in turn increases the shearing of biofilms from the surface of pipes. Changes in water velocity also can be changed by flow of fire hydrants, pipe network design and pipe size, water main breaks, or distribution maintenance practices such as flushing (Smith et al., 1989; Geldreich, 1988).

Tubercles from pipe surfaces are dislodged due to the "hammer" effect which occurs on sudden opening or closing of the pipelines. An affect on the corrosion and on sediment accumulation can be seen due too the variation in the distribution system hydraulics. The accumulation of sediment and a loss in the residue formed by the disinfectant, leads to the growth of microbes, which is cause by the stagnation of water in the pipeline systems. Researchers have developed hydraulic models to monitor the fate of chlorine residuals and their reaction products in distribution systems (Characklis et al., 2988; Clark et al., 1988).

Nutrient availability (nutrients like carbon, nitrogen and phosphorus), other nutrient sources (including certain constructional materials, rubber, silicon, polyvinyl chloride, polyethylene, and bituminous coatings), disinfection residual concentrations, corrosion, sediment accumulation are other factors which favor biofilm growth.

DISCUSSION

How to recognize a biofilm occurrence?

Its is not easy to recognize the contamination occurring in the distribution systems as it can be due to the disruption or it could be the microbial growth in distribution system biofilms. Coliforms can be present through other sources or they can be associated with biofilms. Hence for categorizing if the microbial growth in the biofilm is responsible for an increase in the total coliform levels through treatment practices and proper maintenance of the distribution systems is essential.
The usual methods of monitoring cannot decide this as the contamination may be intermittent. A problem in the treatment system concludes that bacteria are growing in the distribution systems. However, after tracing the reason for contamination, water system should consider the location and should control the growth pf biofilm bacteria, giving special attention to fecal coliform bacteria.

Detection of Breakthrough Contamination

Criteria for Obtaining a Variance to the Total Coliform Rule
Source: U.S.EPA, 1991

The following criteria serve as guidance for states in identifying systems that could operate under a variance without posing an unreasonable risk to health:

1. Over the past 30 days, water entering the distribution is shown to:
    - Be free from fecal coliform or E. coli based on at least daily sampling.
    - Contain less than 1 total coliform/100 mL of influent water in at least 95 percent of all samples based on at least daily sampling.
    - Comply with the total turbidity requirements under the Surface Water Treatment Rule.
    - Contain a continuous disinfection residual of at least 0.2 mg/L.
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2. The system has had no waterborne disease outbreak while operating in its present configuration.

3. The system maintains biweekly contact with the state and local health department to assess illness possibly attributable to microbial occurrence in the public drinking water system.