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Pipe Scales and Biofilm Formation Measurement Using Sensors

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Abstract:- **According to the Urban Drinking Water Distribution Systems (UDWDS), safety and security are two important features. People often compromised by a suite of physical, hydraulic, and chemical factors adversely impacting the quality of potable water reaching consumer taps. Scales and biofilm conglomerates (SBC) with sorption of water chemicals and planktonic microorganisms are recognized as underestimated contaminant sources in ageing pipe networks of UDWDS. The main aim of this study was to provide an updated review of processes and factors associated with the increasing the frequency of deteriorated finished water quality as a result of SBC effects in UDWDS. Important synergistic SBC effects on finished water quality were identified as: Those containing the chemical release from pipe scales due to biofilm-induced alterations at the pipe surface/water interface. The synergistic SBC action on promoting increased release rates of toxic chemicals or pathogens into the water. The microbial enhanced corrosive phenomena on pipe scales and their constituents.**

Keywords**: Biofilms, Drinking water, Environmental health, Exposure, Pipe scales, Urbanization.**

I. INTRODUCTION

Unsafe water sanitation and hygiene is one of the top4 leading global risks for the burden of disease measured in disability-adjusted life years (DALYs) (4% of global DALYs), along with alcohol use and unsafe sex (5% each), and underweight (6%) (WHO, 2009). Globally, unsafe water sanitation and hygiene is by far the leading environmental risk for morbidity when compared with other environmental factors, such as urban outdoor air pollution, indoor smoke from solid fuels, environmental lead exposure, and global climate change (WHO, 2009). Despite improvements in sanitation and hygiene via access to centralized water treatment facilities and advances in water treatment technologies, i.e., reverse osmosis, it is widely accepted that human exposures to waterborne pathogens and episodic events of chemicals release in finished water of urban drinking-water distribution systems (UDWDS) are of considerable magnitude (NRC, 2006; Edwards et al., 2009). Since 1982, the number of waterborne outbreaks in community water systems has been steadily declining in the United States, while the % contribution of DWDS to the overall frequency of waterborne outbreaks is steadily increasing to > 60%. The number of annual waterborne outbreaks may be actually exceeding current estimates, based on the U.S. Government Accountability Office report highlighting the alarming number of health-related breaches in drinking-water going unreported (U.S. GAO, 2011). The drinking water directive (98/83/EC) is currently under scrutiny by EU scientific experts and stakeholders on whether extensive revision is necessary (Jørgensen et al., 2008).Points of water use (home taps, bottled water, etc.) and points within UDWDS (nearly equally in magnitude) represent the two most frequently occurring deficiencies associated with waterborne disease and outbreaks (Lianget al., 2006; Yoder et al., 2008). Growth of pipe SBC coupled with sorption of water chemicals and planktonic microorganisms by SBC has been increasingly recognized as underestimated contaminant sources in UDWDS (Lytleet al., 2004).

II. FACTORS INFLUENCING PIPE SCALE FORMATION

Electrochemical surface corrosive phenomena coupled with dissolution and/or precipitation reactions of metal salts have been primarily charged with induction of pipe scales, pits, tubercles, and nodules formation, often leading to water discoloration (McNeill and Edwards, 2001). In the past, water utilities had relied upon the Langelier index to predict onset of corrosive events in UDWDS associated with leaching of lead, zinc, and copper from brass, bronze, soldered joints, and their respective pipe materials, but this approach was shown to be largely misused, and it was eventually abandoned(AWWA, 1996; Schock and Lytle, 2010).1486 K. C. Makris et al. Depending on the pipe material, various pipe scales have been observed to form in UDWDS. In non-chlorinated water flowing through cast iron pipes, α-FeOOH and calcium carbonate were the primary minerals that comprised pipe scales, while α-FeOOH and magnetite were observed as pipe scale constituents in chlorinated water (Wang et al., 2012a). Pipe scales from cast iron pipes in contact with chloraminated water were shown to be composed of calcium phosphate and α-FeOOH (Wang et al., 2012a). The source of treated water flowing through old unlined cast iron pipes exerted a major influence on the composition of formed pipe scales, since thick tubercles with >1 magnetite: goethite ratio were formed that contained siderite and green rust when treated surface water was flowing through the pipes, whereas in the case of ground water, thin hollow tubercle shells with <1 magnetite: goethite ratio were formed (β-FeOOH, γ -FeOOH) (Yang et al.,2012). In addition to goethite, lepidocrocite, and magnetite, three different type of green rust were found in pipe scales formed on cast iron pipes, including the least stable chloride form of green rust despite the notion that green rusts were not present in drinking water pipe scales (´Swietlik et al.,2012). Porous deposits of iron oxide or oxyhydroxide phases, including magnetite, goethite, and lepidocrocite, formed a shell-like dense layer at the scale–water interface, while a highly porous phase was observed near the pipe surface of galvanized steel or cast iron (Sarin et al., 2001; Lytle et al.,2005Manganese scales were observed to form within iron tubercles of iron pipes, while a brittle thin manganese oxide that was relatively easy to detach was found in PVC pipes(Cerrato et al., 2006).Water pH may exert a major influence on pH-dependent speciation of carbonic acid, thus, affecting $CaCO_3$ deposition and scale formation(Hodgkiess, 2004); a pH increase from 8.8 to 10.0 could increase $CaCO_3$deposition from 2 mg cm^{-2} to 12 mg cm^{-2} in 2 hrs (Andritsos and Karabelas, 1999). A combination of temperature and pH effects increased $CaCO_3$deposition by five times when pH increased from 7.0 to 8.0 at 70◦C temperature(Dawson, 1990).

Oxidation of pipe metallic constituents could be facilitated by the presence of disinfectant agents such as chlorine; lead corrosion products consumed chlorine, facilitating formation of a more stablePbO_2 scale, but its rate of oxidation by chlorine was diminished in the presence of high concentrations of carbonate ions (Liu et al., 2009), or addition of orthophosphate to chlorinated water (Lytle et al., 2009), or natural organic matter that was shown to inhibit formation of cerrussite in lead pipes, forming amorphous films (Korshin et al., 2005). Phosphate addition as corrosion inhibitor has been widely used in UDWDS, particularly for lead pipe Pipe Scales and Bio films in Drinking-Water Distribution Systems 1487network systems (Edwards and McNeill, 2002; McNeill and Edwards, 2002).Natural organic matter indirectly influences pipe scale formation, because of its affinity to form soluble complexes with primary pipe scale constituents, such as Fe and Al (Campbell and Turner, 1983). Lower molecular weight organic acids (fulvic acids) could form soluble complexes with metals, like copper in finished water, minimizing the formation of pipe scale precipitates.

Fig.1.1: Formation of pipe scales

III FACTORS INFLUENCING BIOFILM FORMATION

Bio film formation may be influenced by factors, such as magnitude of residual concentration of disinfectant agent, establishment of conditioning film, bio availability of inorganic nutrients in finished water, hydraulic conditions, pipe material type and surface properties, water flow velocity, water pH, and water temperature (Norton and LeChevallier, 2000; Van der Kooij andVeenendaal, 2001). Microbial growth rates are generally slower in a bio film colony when compared with those of planktonic cells. The bio film environment though, can offer a protective environment for anchored microbes against the action of disinfectants used (Van der Wende et al., 1989). The biofilm environment is believed to protect cells against the activity of chlorinevia diffusional resistance and neutralization of chlorine when in contact with EPS constituents (e.g., alginate) and pipe material (Van der Wende et al.,1989).A prerequisite of bio film formation is the establishment of a conditioning film used by planktonic bacteria to sorb onto pipe surfaces (Bakkeret al., 2004). Conditioning films are formed through the adsorption of proteins, lipids, nucleic acids, and other natural surface active agents onto pipe surfaces. EPS production is instrumental towards biofilm stability and integrity(Vandevivere and Kirchman, 1993; Danese et al., 2000). In P. aeruginosa bio films, production of EPS such as the capsule-like polysaccharide called alginate could down regulate flagellum synthesis and therefore motility(Garrett et al., 1999), turning the bacteria from a motile to a mucoid phenotype(Hentzer et al., 2001). This mucoid conversion is indicative of the overproduction of alginate, which could either facilitate bacterial adherence to pipe surfaces, or it could serve as a barrier to phagocytosis, or as a reactant to neutralize oxygen radicals (Hentzer et al., 2001). A mucoid strain could develop a more structurally heterogeneous bio film than that produced by a comparable non-mucoid strain (Hentzer et al., 2001). Increases in metal divalent cation concentrations (calcium) in bio film growth medium significantly increased bio film production for Pseudomonas spp. (Turakhia and Characklis, 1989). It was speculated that Ca2+ ions formed complexes with alginate, producing a gelly-type of external surface, offering enhanced stability to bio film structure (Chen and Stewart, 2002). Iron pipe constituents could also provide essential nutrients in water for microbial growth, including organic carbon, phosphorus, and nitrogen (Mortonet al., 2005). The adherence of surface active biomolecules to pipe surfacesnot only improved access of bacteria to nutrient media, but also perturbedpipe surface properties, such as hydrophobicity and roughness (Beveridgeet al., 1997; Bakker et al., 2004). Although certain authors reported that microorganisms attached to a greater extent onto hydrophobic rather than ontohydrophilic surfaces (Flemming and Wingender, 2001; Donlan, 2002), it was suggested that the affinity to hydrophobic surfaces could be additionally ascribed to the nature and surface properties of attached bacterial strains (Bakker et al., 2004). Microorganisms undergo vast changes during their transformation from planktonic cells to adhered cells on pipe surfaces. In biofilm colonies, bacteriat end to adapt to environmental changes via gene expression mechanisms(Costerton, 1999; Donlan and Costerton, 2002). In P. aeruginosabiofilms, patterns of genetic differentiation showed that 40% of proteins incellular walls were different from those of planktonic cells (Potera, 1999);

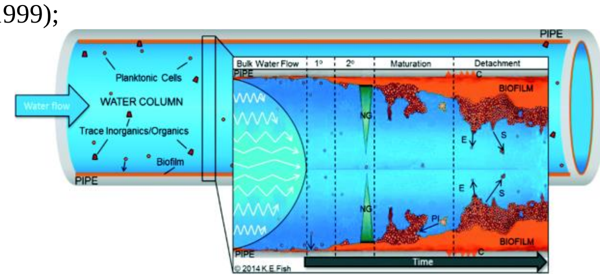

Fig 1.2 Formation of bio films

such changes were reflected upon the new phenotypic characteristics developed by bacteria in bio films due to various environmental stimulating signals(O'Toole and Kolter, 1998). Pseudomonas aeruginosa and P. fluorescens willeasily form bio films under nearly all environmental conditions (O'Toole and Kolter, 1998), whereas certain strains of Escherichia coli K-12 and Vibriocholerae will not form bio films in minimal medium, unless supplemented with amino acids (Pratt and Kolter, 1998; Watnick et al., 1999).Cell hydrophobicity better explained surface adhesion to polystyrene surfaces than less hydrophobic bacterial cells (Van Loosdrecht et al., 1987).Tendolkar et al. (2004) investigated Esp, a surface protein in Enterococcusfaecalis which had been reported to regulate bacterium's surface adhesion potential. Esp positive strains were more hydrophobic and attached better to polystyrene, polypropylene, and PVC surfaces than Esp negative strains, confirming the positive relationship between cell hydrophobicity and pipe surface attachment potential. It has been also demonstrated that both the presence of flagella per se and flagellar motility could positively influence bacterial attachment to surfaces (Donlan, 2002; Klausen et al., 2003; Lemonet al., 2007). Although fimbriae do not directly participate in bio film formation, their presence promotes the process of bacterial adhesion to surfaces(Inoue et al., 2003) probably by overcoming the initial electrostatic repulsion barrier that exists between the cell and substratum (Corpe, 1980).The effect of various pipe material types on the growth of bio films has been widely studied, suggesting lower bio film growth rates in plastic pipes. For example, plastic materials supported the growth of bio films, but the growth in plastic pipes was the same, if not lower than that in iron, steel, or asbestos/cement (Niquette et al., 2000; Zacheus et al., 2000). Biofilm growth in UDWDS was significantly lower on polymeric materials (PE, PVC, and Teflon) than that of iron metallic pipes, such as gray iron, cast iron, galvanized steel, cemented steel, cemented cast iron, or asbestos/cement (Kerret al., 1999; Niquette et al., 2000; Momba and Kaleni 2002). The enhance biofilm growth in metallic pipes versus those in plastics was partially attributed to the formation of iron corrosion products that served as physical protective barrier of biofilm communities against the effects of increased flow rates and residual disinfectant concentration. Van der Kooij and Veenendaal(2001) and Clark et al. (1994) observed that biofilm formation was enhanced in PE > PVC, while others concluded no significant difference in colonization magnitude and rates between PE and PVC materials (Pedersen, 1990;Zacheus et al., 2000; Wingender and Flemming, 2004). Chan (2003) found that biofilm re growth on pipes made of rough surface materials such as cast iron, concrete-lined cast iron, and galvanized steel was greater than that on smooth-surface PVC pipe. Lehtola et al. (2004)

used phospholipid fatty acid analysis to show higher number of gram-negative bacteria in biofilm established on copper pipe than on PE pipes, but there was no significant difference in biofilm formation between copper and PE pipes after 200 days of reaction. Pipe material can also influence composition and biomass density of attached microbes (Schwartz et al., 1998; Niquette et al., 2000; Lehtola et al.,2005; Silhan et al., 2006; Zhou et al., 2009). Plastic materials, such as polyethylene(PE) and PVC, rapidly colonized (within a few days) in significantly higher densities than those observed for steel and copper (Schwartz et al.,1998). Fewer bacteria have been shown to attach to copper pipes compared with stainless steel pipe material (Zhou et al., 2009), and this perhaps could be attributed to the toxic effect that soluble copper ions impart upon several bacterial species. Lehtola et al. (2004) reported that the formation of biofilm was slower in copper pipes than in PE pipes, and that copper ions led to lower microbial numbers in water. Van der Wende et al. (1989) suggested that at increased flow rates (15 cm hr−1) when compared with lower flow rates(4.5 cm hr−1), nutrient availability was greater, thereby enhancing biofilm cell growth rates (0.006 hr−1). The observed increase in counts of planktonic cells in flow systems was not related to a higher cell growth rate, but to higher cell detachment from adhered bacteria (Van der Wende et al., 1989;Manuel et al., 2007). Nevertheless, at flow velocities as high as 3 m cell detachment increased, thus, adversely impacting biofilm growth rates (Cloeteet al., 2003).

The anticipated pH effect on bacterial attachment and biofilm formation seems to be organism dependent. Certain microorganisms, such as Xylellafastidiosa, appeared to be highly sensitive to small pH changes, being able to produce cell aggregation, attach to surfaces, and finally form biofilm atpH 6.8, but not at <pH 6.2 (Wulff et al., 2008). Other typical UDWDS microorganisms, Pseudomonas and Klebsiella, were able to form biofilms under a wider range of pH (3–10); however, biofilm thickness at pH 3 was reduced to 70% of that at pH 8 (platinum wire electrodes) (Stoodley et al.,1997). Depending on the microorganism, finished water temperature effects on biofilm dynamics are expressed via the gene activation/deactivation mechanisms, encoding surface adhesion potential (Fitzpatrick et al., 2005; Lemonet al., 2007). The magnitude of surface adhesion force is usually based upon measurements of Lifshitz–van der Waals and electrostatic acid–base forces (Smets et al., 1999; Gallardo-Moreno et al.,2002a, 2002b).

IV. DESTABILIZATION OF PIPE SCALESCHEMICAL RELEASE

That the design of the new non adhesive material are on the ease with which the initially adhering microorganisms are detached rather than initial microbial adhesion. The differences in detachment rates between rubber and stainless steel on the basis of stronger attachment to rubber was explained by Smoot and Pierson in 1998.the same studied showed that cell detachment from rubber was not significantly affected by growth pH, but by temperature.
Surface roughness with rougher surfaces showing less cell detachment can also affect Cell detachment. processes such as secretion, shedding of cell surface material, cell lyses, and nutrient sorption processes from the surrounding water environment may control The EPS composition. Cavity formation, which occurs beyond the point of biofilm maturation, can be largely responsible for weakening microbial adhesion. Cells may also communicate via QS, which may in turn affect various biofilm processes, the mechanism of gene regulation in which bacteria use chemical signals to monitor their own population density and to control expression of specific genes in response to population density is known as QS. Wild types and Mutants were able to produce biofilms, however, only wild type cells were able to form a mature biofilm in the presence of microcolonies and water channels. Mutants were only able to form monolayers, suggesting that QS in P. aeruginosa was responsible for biofilm differentiation, even though it was not involved in the attachment process.

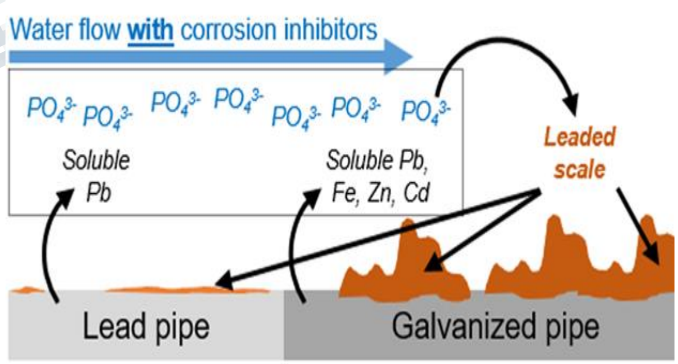

Fig 1.3: Destabilization of pipe scales

An established biofilm provides an optimal environment for the exchange of genetic material between cells, however, the degree of genetic exchange tends to be lower within a biofilm, adversely impacting microbial sensitivity to antibiotics, surfactants, and sanitizers.

V. BIOFILM EFFECTS ON FINISHED WATER QUALITY

Some of the notable effects of biofilms in UDWDS relate to:
(i) microbial induced corrosion (MIC)
(ii) loss of indicator organism utility
(ii) taste, colour, and odour problems
(iv) disinfectant consumption.

Microbial Induced Corrosion

Corrosion of pipe surfaces represents a major risk factor in physical and hydraulic integrity of UDWDS. The main factors influencing pipe surface corrosion are pipe material type, water corrosivity, the soil/water quality external to pipe, and microbial activity in the pipe biofilm. Over time, corrosion may become serious enough to restrict water passage, causing accelerating biofilm formation and pipe breaks.

Loss of Indicator Organism Utility

A pipe biofilm structure may compromise the effectiveness of total coliform tests as an indicator of drinking-water quality in two major ways. First, a high level of heterotrophic bacteria in pipe biofilm and suspended sediment particles may interfere with the analysis of total coliforms. Second, biofilm coliforms could detach into finished water, resulting in coliform-positive samples, a coliform-positive test under the aforementioned conditions could suggest growth of other microbes as well, including opportunistic pathogens.

Taste, Colour and Odour Problems

Water discoloration, taste and odour issues, may result from a number of reactions, some of which are microbial mediated. The types of microbes often associated with aesthetic issues in drinking water are, iron and sulphur bacteria. Sulphate-reducing bacteria were found within the structure of iron and copper corrosion scales in UDWDS and they were associated with taste complaints to elevated sulphides and the visual coloration of finished water, one general cytotoxin which inhibits protein synthesis (cylindrospermopsin), and a group of toxins termed microcystins that inhibit protein phosphatases (Chorus and Salas, 1997).

Disinfectant Consumption

Biofilms react with chemical disinfectants thus decreasing residual disinfectant concentration in water available for planktonic pathogen inactivation. An extensive biofilm may decrease disinfectant levels to minimum, rendering it inadequate to protect the public from waterborne outbreaks. Use of chloramines as a disinfectant often results in faster disinfectant decay due to nitrification in lead pipes. Nitrification-induced pH drop could increase Pb leaching from lead pipes depending on the magnitude of initial alkalinity and activity of nitrifying bacteria. Disinfectant decay was noted with water age, particularly in chlorinated simulated water distribution systems, resulting in increased microbial detection frequencies and densities with water age. Chlorine contact with bacterial exopolymeric.

VI. BIOFILMS IN UDWDS AND HEALTH RISKS

Public health threats associated with biologic agents in UDWDS typically refer to bacteria, viruses, protozoa, invertebrates, algae and algal toxins, fungi and microbial toxins. All known exposure pathways, such as ingestion of contaminated water, inhalation of contaminated aerosols, and dermal absorption during washing, showering, and bathing, are under consideration in a comprehensive human exposure assessment for chemicals/toxins and pathogens found in home taps of urban consumers. Diarrhea is the main end point of disease used to calculate the percent contribution of lack of access to safe water sanitation and hygiene to the overall morbidity and mortality figures, but in recent years, other outcomes related to the presence of chemicals/toxins emerge, hinting towards additional contributors/risk factors that could be accounted for in the pertinent burden of disease calculations. schools, hospitals, and other health care facilities as biofilm-borne pathogens, could considerably contribute to water-associated nosocomial infections.

VII. IMPLEMENTATION

In our proposed method, Raspberry PI B+ is used as a core controller. The raspberry pi is run on LINUX kernel by the use of keyboard and monitors the LINUX OS is boot on to the Raspberry PI. The temperature sensor, conductivity sensor, turbidity sensor, dissolved oxygen sensor, Ph sensor can be read directly from the command line.

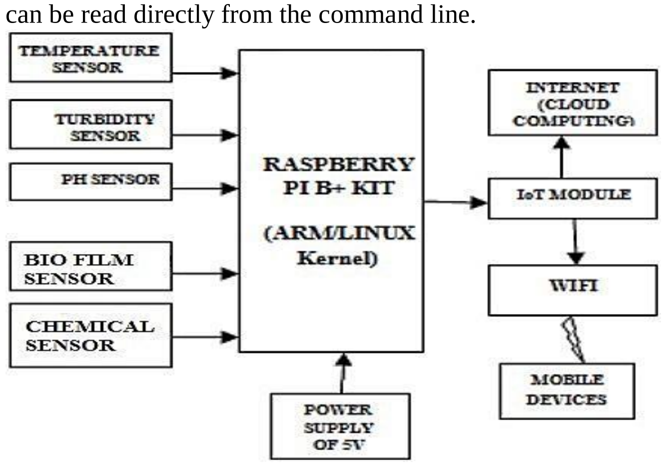

Fig 1.4:Sensors used to measure biofilms and contamination in water pipes

However, this requires us to input a command every time we want to know the sensors reading. In ordered to access all the terminals of the sensors, python program is used, which will read the sensors value automatically at set time intervals. The Raspberry Pi comes equipped with a range of drivers for interfacing. However, it's not feasible to load every driver when the system boots, as it will increase the boot time significantly and use a considerable amount of system resources for redundant processes. These drivers are therefore stored as loadable modules and the command modprobe is employed to boot them into the Linux kernel. Then Raspberry Pi sends the data to the IoT. The IoT module send the data to internet using cloud computing and also to WIFI for accessing mobile devices. The hardware circuit diagram for connecting iot module (USR-WIFI232-X-V4.4) with Raspberry Pi is shown in figure 2. Figure 2: Circuit diagram for connecting core controller to IoT module Then the monitoring parameters of the water from the sensors are transmitted through IoT module to the gateway. The gateway is responsible for data analysis and forward sensing data to the remote server. The server collects sample data by receiving the UDP packets containing sample data from the IoT module and gateway and store in database. By using a separate IP address we can view the sensor data anywhere in the world.

Sr no.	Parameter	Technique used	WHO standard	Indian Standard
1	Temperature	Thermometer	-	-
2	Color	Visual / color kit	-	5 Hazen units
3	Odour	Physiological sense	Acceptable	Acceptable -
4	pH	pH meter	6.5 – 9.5	6.5 – 9.5
5	Dissolved oxygen	Redox titration	-	-
6	Total Hardness	Complexometric titration	200 ppm	300 ppm

Table 1.1: Parameters affecting water quality

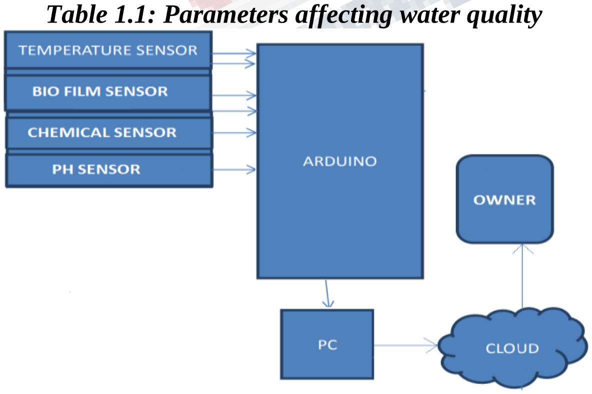

Fig 1.5:Delivering contamination data to owner

VIII. CONCLUSION

A biofilm is a collection of organic and inorganic, living and dead material collected on a surface. It may be a complete film or, more commonly in water systems, small patches on pipe surfaces. Biofilms in drinking water pipe networks can be responsible for a wide range of water quality and operational problems. Biofilms can be responsible for loss of distribution system disinfectant residuals, increased bacterial levels, reduction of dissolved oxygen, taste and odor changes, red or black water problems due to iron or sulfate-reducing bacteria, microbial-influenced corrosion, hydraulic roughness, and reduced materials life. Microorganisms in biofilms can include bacteria (including coccoid round, rod-shaped, filamentous, and appendaged bacteria), fungi, and higher organisms like nematodes, larvae, and Crustacea. Therefore, it is important to thoroughly flush thedistribution system to remove these organisms following a contamination event.

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