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Review

Potential impacts of changing supply-water quality on drinking water distribution: A review

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ABSTRACT

Driven by the development of water purification technologies and water quality regulations, the use of better source water and/or upgraded water treatment processes to improve drinking water quality have become common practices worldwide. However, even though these elements lead to improved water quality, the water quality may be impacted during its distribution through piped networks due to the processes such as pipe material release, biofilm formation and detachment, accumulation and resuspension of loose deposits. Irregular changes in supply-water quality may cause physiochemical and microbiological de-stabilization of pipe material, biofilms and loose deposits in the distribution system that have been established over decades and may harbor components that cause health or esthetical issues (brown water). Even though it is clearly relevant to customers' health (e.g., recent Flint water crisis), until now, switching of supply-water quality is done without any systematic evaluation. This article reviews the contaminants that develop in the water distribution system and their characteristics, as well as the possible transition effects during the switching of treated water quality by destabilization and the release of pipe material and contaminants into the water and the subsequent risks. At the end of this article, a framework is proposed for the evaluation of potential transition effects.

Contents

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1. Introduction

1.1. Drinking water supply system

Drinking water treatment makes water potable by removing contaminants present in the source water. Depending on the contaminants present, different technologies and their combinations can be used for drinking water production (Moel et al., 2006). In both developing and industrialized countries, a growing number of contaminants are entering water supplies due to human activity: heavy metals, pharmaceuticals, endocrine disruptors, perfluorinated compounds, flame retardants or biocides (Shannon et al., 2008; Schriks et al., 2010; Ternes et al., 2015). Public health and environmental concerns drive efforts to tighten water quality regulations (WHO, 1996; WHO, 2004; WHO, 2011; Qu et al., 2012) and further treat waters previously considered clean. These efforts have greatly promoted the development of water treatment science and technology and the upgrading of treatment plants over several decades (Pinheiro and Wagner, 2001; Miner, 2002; Shannon et al., 2008).

The treated drinking water is delivered to individual dwellings, communal buildings and other customers' through pressurized distribution networks (DNs), including drinking water distribution systems (DWDSs) and premises plumbing (Mays, 1999; Ainsworth, 2013). Those DNs - consisting of pipes, pumps, valves, storage tanks, reservoirs, meters, fittings, and other hydraulic appurtenances transport the drinking water from a centralized treatment plant or well to customers' taps (Moel et al., 2006; NRC, 2006). In general, DWDSs are buried underground, range in length of tens to several hundreds of kilometers (totaling 0.4 million kilometers in the Netherlands and1.6 million kilometers in the U.S.) with varying diameters and materials (metals, plastic, and cement pipes) in multi-loops (Verberk et al., 2007; Vreeburg, 2007; AWWA, 2012). Premise plumbing refers to the parts of DN that connect a building to the water main pipe and the pipes inside buildings, which are characterized by high surface area to volume ratio, long retention times, warmer temperature, and close contact with water (NRC, 2006; Nguyen et al., 2012; Wang et al., 2013; Proctor and Hammes, 2015). The DNs is the final barrier that protects drinking water from contaminants during distribution and ensures the quality of the supplied product (Mays, 1999). For the drinking water provision, distribution is as important as production, because the quality of tap water can only be as good as the condition of the pipes it flows through (Moel et al., 2006; Misko et al., 2010; Ainsworth, 2013).

1.2. Water quality stability and deterioration during distribution

There is a broad consensus that the ultimate goal of drinking water supply should be seen as providing good quality at the customer's tap rather than only at the point it leaves the treatment plant. The treated drinking water enters the distribution system containing physical loads (particles), microbial loads (cells) and nutrient loads (organic and inorganic nutrients) (Liu et al., 2013c; Prest et al., 2016). Given the occurrence the long retention times (also referred as "water age") especially at the dead-end nodes (Ainsworth, 2013) and in premises plumbing the simultaneously impact of physiochemical and microbiological processes can result in the deterioration of the quality of the water that reaches customer's tap compared to the original water produced at the treatment plant (Vreeburg and Boxall, 2007; Liu et al., 2013c; Proctor and Hammes, 2015). Such water quality deterioration has been observed and reported worldwide: for example in higher turbidity and particle counts (Vreeburg et al., 2004; Verberk et al., 2007; Liu et al., 2016), larger cell numbers (Van der Kooij, 1992; Hammes et al., 2010; Liu et al., 2016), and greater presence of selected indicator micro-organisms (van der Wielen et al., 2016) at taps compared to treatment plants. In extreme cases, discolored water (also reported as dirty water, red water) (Sly et al., 1990; Vreeburg and Boxall, 2007; Li et al., 2010) was observed at the taps.

Those observed quality deteriorations are related to the accumulation of distribution network harbored material (DNHM) and ongoing processes such as pipe corrosion, biofilm matrix formation and detachment, loose deposit accumulation and resuspension, which occur in the DN pipes over decades (Lee et al., 1980; LeChevallier et al., 1987; Van Der Wende et al., 1989, Smith et al., 1997; Gauthier et al., 1999; Chaves Simões and Simões, 2013, Liu et al., 2014) (Fig. 2A). Consequently, to guarantee the delivery of high quality water to customers, the concept of water quality stability was proposed and set. The standards included: re-suspension potential measurements (RPM, turbidity < 0.8NTU) for physical stability (Vreeburg et al., 2008); a saturation index (SI, -0.2 to 0.3) for chemical stability (Verberk et al., 2009); and assimilable organic carbon limit (AOC, < 10 μg C/l for unchlorinated water) for biological stability (Van der Kooij, 1992). Achieving these stability standards has become another important driving force behind the upgrading of treatment processes (Pinheiro and Wagner, 2001; Miner, 2002; Qu et al., 2012).