Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Systematic tracking, visualizing, and interpreting of consumer feedback for drinking water quality

Andrea M. Dietrich [a,b,*], Katherine Phetxumphou [a], Daniel L. Gallagher [a]

[a] Department of Civil and Environmental Engineering, Virginia Tech, 418 Durham Hall, Blacksburg, VA 24061-0246, USA
[b] Department of Food Science and Technology, Virginia Tech, 360 Duck Pond Drive, Blacksburg, VA 24061, USA

ARTICLE INFO

Article history:
Received 14 May 2014
Received in revised form
1 August 2014
Accepted 5 August 2014
Available online 14 August 2014

Keywords:
Odors
Drinking water
Visualization
Consumers
2-MIB
Dimethyl trisulfide

ABSTRACT

Consumer feedback and complaints provide utilities with useful data about consumer perceptions of aesthetic water quality in the distribution system. This research provides a systematic approach to interpret consumer complaint water quality data provided by four water utilities that recorded consumer complaints, but did not routinely process the data. The utilities tended to write down a myriad of descriptors that were too numerous or contained a variety of spellings so that electronic "harvesting" was not possible and much manual labor was required to categorize the complaints into majors areas, such as suggested by the Drinking Water Taste and Odor Wheel or existing check-sheets. When the consumer complaint data were categorized and visualized using spider (or radar) and run-time plots, major taste, odor, and appearance patterns emerged that clarified the issue and could provide guidance to the utility on the nature and extent of the problem. A caveat is that while humans readily identify visual issues with the water, such as color, cloudiness, or rust, describing specific tastes and odors in drinking water is acknowledged to be much more difficult for humans to achieve without training. This was demonstrated with two utility groups and a group of consumers identifying the odors of orange, 2-methylisoborneol, and dimethyl trisulfide. All three groups readily and succinctly identified the familiar orange odor. The two utility groups were much more able to identify the musty odor of 2-methylisoborneol, which was likely familiar to them from their work with raw and finished water. Dimethyl trisulfide, a garlic-onion odor associated with sulfur compounds in drinking water, was the least familiar to all three groups, although the laboratory staff did best. These results indicate that utility personnel should be tolerant of consumers who can assuredly say the water is different, but cannot describe the problem. Also, it indicates that a T&O program at a utility would benefit from identification of aesthetic issues in water.

1. Introduction

Consumer feedback on drinking water quality is an important data stream that is available to utilities as one element for assessing the quality of drinking water distributed to residences and businesses. Many governments [e.g., United States (USEPA, 2008), Australia (Australian Drinking Water Guidelines, 2011), United Kingdom (DWI, 2009), City of Philadelphia (PWD, 2013)] and researchers [e.g., (Dietrich, 2006;

* *Corresponding author*. Department of Civil and Environmental Engineering, Virginia Tech, 418 Durham Hall, Blacksburg, VA 24061-0246, USA.
E-mail address: andread@vt.edu (A.M. Dietrich).
http://dx.doi.org/10.1016/j.watres.2014.08.007
0043-1354/

Hrudey and Hrudey, 2007; Burlingame and Mackey, 2007; Murray et al., 2010)] advocate consumer complaint surveillance (CCS) as a valuable process control to augment chemical and microbiological water quality monitoring. Consumer complaint surveillance refers to a methodology that relies on detecting water quality problems based on consumer input. When implemented as a process control feature for assessing and maintaining water quality in the distribution system, CCS will contribute to a hazardous contaminant warning system (CWS) (USEPA, 2008; PWD, 2013) and an early detection of aesthetic issues that are problematic for consumers and the water industry (Gallagher and Dietrich, 2014).

Since consumers are real-time sensors who continuously monitor water quality everywhere and everyday throughout the water distribution system, they are uniquely positioned to provide feedback. Their feedback can be specific, such as the level of chlorinous odor has changed, or general, such as the water looks, tastes, or smells "different". The ability to describe a specific taste or odor is challenging both for consumers and those trained in sensory analysis (Czerny et al., 2008). The focus of this article is the initial process used to identify aesthetic issues, which involves consumers in conjunction with utility personnel describing the issue.

When consumers report an aesthetic water quality issue, a three-prong process can be used by the water industry to establish process control for the taste, odor, or appearance (color and/or particles) issue in drinking water:

1. Apply sensory analysis to describe the aesthetic issue.
2. Apply chemical analysis to determine the identity and concentration of the sensory compound(s) when the issue cannot be resolved based on sensory data.
3. Once the cause of the aesthetic issue is identified, treat and control to minimize or remove.

The effectiveness of describing aesthetic issues in drinking water is key to resolving them and depends on: 1) limits of the human senses to detect and describe a taste, odor, color, turbidity, or particles; 2) common and accurate language in the dialog with consumers and within and among utilities; and 3) tracking and categorizing consumer feedback by utility personnel. Consumers vary in their ability to detect and describe sensory issues (Lawless and Heymann, 2010), however, they are watchmen to water quality problems.

1.1. *The human senses and perception of drinking water*

The senses of taste and odor are called the chemical senses, as these two senses use receptors to detect specific chemical agents in drinking water from mg/L down to pg/L concentrations (Díaz et al., 2005; Dietrich, 2006; Piriou et al., 2009). Together, taste and odor produce the sensation of flavor. Humans can more readily detect a difference in taste and odor than describe the difference. Hence, the detection threshold, when a person can detect the sensation, but not necessarily describe it, is typically 2–4 fold lower than the recognition threshold, which is the concentration where a person can describe the taste, odor, or difference (Czerny et al., 2008; Lawless and Heymann, 2010). While odors are difficult for humans to classify and describe, visual cues are easier to describe and identify (Köster, 2005). Thus, appearance complaints would be more consistent than taste and odor complaints.

There is variability within the human population for individual thresholds that is best described by a range. Nonetheless, it is common to report just a single value for a threshold concentration for a population. These single values are determined through statistical methods that include geometric means or logistic regression that calculate the level at which 50% of the population detects a stimulus (Meilgaard et al., 2006; Gallagher and Cuppett, 2007; Lawless and Heymann, 2010; Lawless, 2010).

Normal humans vary in their chemical sensory capabilities due to age, genetics, health, mood, temperature, test location, time of day, and sample matrix (Dietrich, 2006; Mirlohi et al., 2011). This results in taste and odor thresholds varying by a factor of one hundred or more from individual to individual. Variable thresholds for individuals have been reported for many compounds present in drinking water, including: nonadienal (Burlingame et al., 1992); haloanisoles (Díaz et al., 2005); cupric ion (Gallagher and Cuppett, 2007; Dietrich, 2009); geosmin and 2-methylisoborneol (2-MIB) (Piriou et al., 2009); ferrous and ferric ion (Ömür-Özbek and Dietrich, 2010); methyl-t-butyl ether (Lawless, 2010); and manganese (Sain et al., 2014). Thus, not all consumers can detect an aqueous sensory problem for taste and odor even if it is present in drinking water.

Water has different tastes, odors, and appearances, and just like in food, consumers are able to notice when the water's sensory characteristics change. Personal choices in drinking water are influenced by: 1) psychological factors, including personal experience, memory, and external stimuli; 2) physiological factors, such as biochemistry, physical body factors, health; and 3) external factors, such as humidity and temperature (Dietrich, 2006). The flavor of drinking water can come from multiple causes: 1) the chemical and microbial content of the natural water due to geology and ecology; 2) chemicals added/removed during the treatment process; and 3) inputs and reactions that occur during distribution and storage. No matter if it is treated tap water or bottled water, people are accustomed to their local water quality and will detect even the slightest changes. Consumers dislike inconsistency in the taste, odor, and appearance of their drinking water because they often associate the changes with bad palatability and increased risk even if the changes in flavor are due to benign factors, such as seasonal variation (Dietrich, 2006; Burlingame and Mackey, 2007; Doria, 2010).

1.2. *Utilities and consumer feedback*

Many utilities respond individually to every water quality complaint (Lauer, 2004). While tracking the total number of consumer complaints is valuable, understanding the number and types of complaint descriptors is more valuable for identifying the aesthetic issue and implementing process control. Categorizing aesthetic complaints is currently a challenge to the water industry, which has yet to adopt standardized descriptors or categories even though they are available. The taste-and-odor wheel for drinking water could provide a common global language as it contains categories