Evaluation of Home Tap Water Quality and Microbial Contamination of Household Filtration Systems.

Authors:
Dr. Douglas Collins, Chief Technology Officer
&
Justin Wang, Chief Executive Officer
(LARQ)

"The shortcomings of existing countertop water filtration systems leave the consumer with the unacceptable dilemma of choosing between consuming the chemicals present in their unfiltered water or exposing their families to the risk of microbial contamination."

LARQ

I. Introduction & Background

Failing public water treatment infrastructure

To supply homes with drinking water, the United States largely depends on a network of aging underground pipes, many of which are reaching, or have exceeded, the end of their useful life. The number of water main breaks across the country, from Syracuse to Los Angeles, is a staggering: 240,000 per year, according to one estimate.[1]

The issues of America's water infrastructure system go much further than Flint, Michigan. A recent report from the NRDC found that more than 27 million Americans are served by water systems violating health-based standards established in the Safe Drinking Water Act.[2] These violations have real world health impacts. An estimated 19 million Americans may become ill each year as a result of drinking contaminated water.[3]

Not only do sources of potential contamination emerge from municipal water treatment facilities, oftentimes aging infrastructure and pipes lead to contamination between the water treatment facilities and the home tap, that is never detected.

A separate concern is the more than 40 million Americans who rely on private wells for their drinking water. These private wells are not regulated by the Federal Safe Drinking Water Act, and typically not by state law either. Consequently, there is very little information on the frequency, or magnitude, of microbial or chemical contamination of these sources. Unless they invest in a regular testing regimen, these users have little to no assurance about the quality of the water their families are consuming.

Shortcoming of existing filtration technology

Only about half of the population takes steps to treat and filter drinking water. By far the most common sys -tems are carbon-based filters deployed in countertop and built-in refrigerator filters.[4] While improving flavor and odor, many of these popular loose carbon media filters are often ineffective against the range of contaminants present in our drinking water. As an example, a study of Boil Water Advisories in the United States, from 2012-2014, found that nearly 21,000 municipalities across the U.S. issued Boil Water Advisories for microbial contamination over those 3 years.[5] What is more, filter usage is notoriously difficult to track, and many consumers do not replace filters in a timely manner.

Further removal of chlorine from tap water can itself pose a risk to drinking water quality. Chlorine provides "residual protection" against microbial contamination. With this protection removed, drinking water is a risk from contamination by the ambient or more typically by the filter system itself. In some cases, the filtered water contained a whopping 10,000 times the bacteria colony count as tap water (many of which were virulent).[6] This leaves the consumer with the unacceptable dilemma of choosing between consuming the chemicals present in their unfiltered water or exposing their families to the risk of microbially contamination.

As such, we wanted to understand the shortcomings of existing filter designs in addressing potential reverse contamination.

---

[1] *2013 Report Card For America's Infrastructure: Drinking Water. ASCE Infrastructure Report Card . https://2013.infrastructurereportcard.org/a/documents/Drinking-Water.pdf. Published 2014.*
[2] *Water, Health, and Equity: The Infrastructure Crisis Facing Low-Income Communities & Communities of Color — and How to Solve It. https://www.nrdc.org/sites/default/files/media-uploads/cwfa_infrastructure_health_equity_white_paper_-_oct_2018.pdf. Published October 2018*
[3]*Duhigg C. Millions in U.S. Drink Dirty Water, Records Show. The New York Times. https://www.nytimes.com/2009/12/08/business/energy-environment/08water.html. Published December 8, 2009.*
[4] *U.S. Drinking Water Filtration and Treatment Survey. NSF International. https://www.nsf.org/knowledge-library/drinking-water-filtration-treatment-survey.*
[5] *Boil Water Advisories in the U.S. https://www.wqa.org/Portals/0/WQRF/ResearchStudy_BoilWaterAlerts-ExecSummary.pdf . Published 2016.*
[6] *Daschner FD, Rüden H, Simon R, Clotten J. Microbiological contamination of drinking water in a commercial household water filter system. https://pubmed.ncbi.nlm.nih.gov/8740859/. Published 1996.*

II. Study Introduction

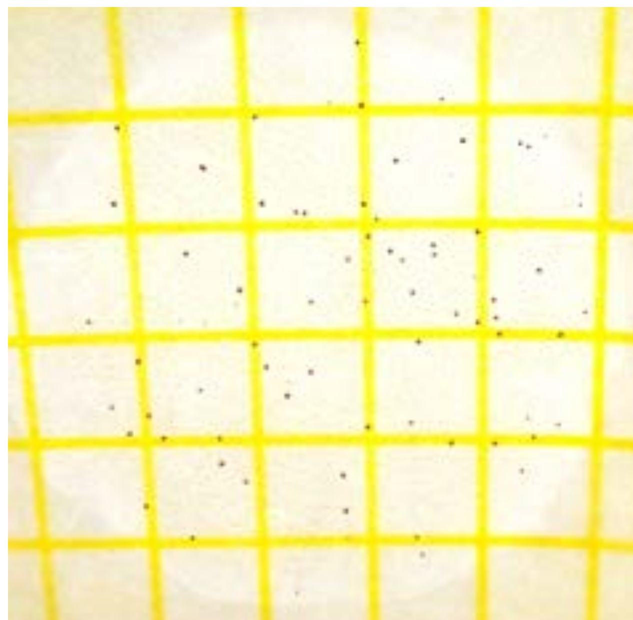
The objective of this study was to evaluate common water filter pitchers as a potential source of microbial contamination. Two widely available water filters were tested: one designed primarily to improve the color, taste and odor of water (Color, Taste, Odor Filter or CTOF), and one intended to substantially eliminate many harmful compounds like mercury and lead (Lead Removal Filter or LRF). Both filters were tested with chlorinated and unchlorinated feedstock water.

In this study we tested for the presence and concentration of heterotrophic bacteria (variously called heterotrophic, aerobic, or total plate count.) This broad class of bacteria, while not necessarily harmful, are a simple and direct measurement of the presence and evolution of bacterial contamination. Similar tests are widely used to monitor the health of water treatment and delivery systems[7] and the US EPA and WHO set allowable limits[8] for potable water. In particular, increases in the heterotrophic bacterial counts are associated with biofilm formation[9] and can be used to pinpoint sources of bacterial contamination.[10]

In all cases, we found bacterial contamination of the filtered water, in some cases in less than two weeks after commissioning a new filter. Chlorinated input water delayed the onset of bacterial contamination of the CTOF but did not eliminate it. In contrast, chlorinated water had little impact on bacterial contamination of the LRFs we tested. These LRFs showed extremely high levels of contamination well before the manufacturer's rated lifetime, indicating serious shortcomings in the filter's design.

III. Materials & Methods

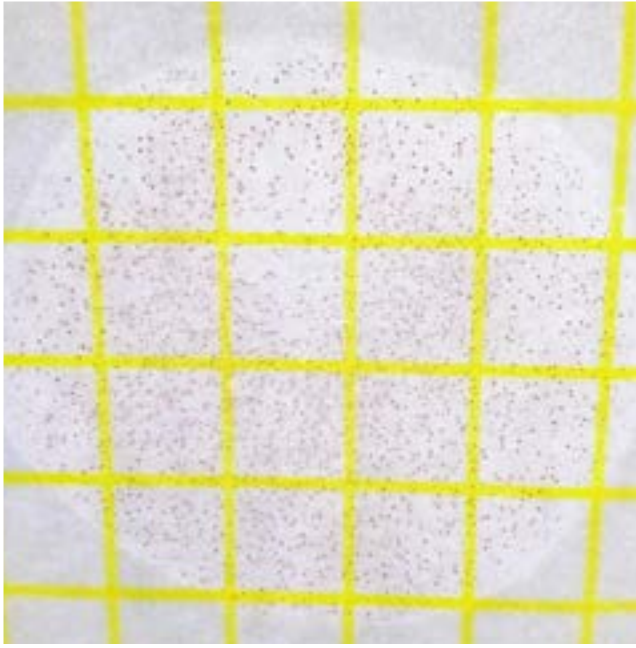
Using the commercial filters described above, we processed 1 liter of filtered water twice a day per filter. We recorded the total time to filter the water and collected samples for culturing. 2 ml samples of the processed water were then cultured on petri film supplied by 3M according to the manufacturer's instructions, and incubated at 36 °C for at least 18 hrs. Typically, both raw and diluted water samples were cultured to increase the range of measurable bacterial concentrations using a general plating primer, and samples were periodically replicated to ensure accuracy. Photos of the incubated water samples were then fed into the OpenCFU software suite for analysis.



Bacterial concentration of tap water after a 48-hour incubation period

---

[7] *Bartram J, Cotruvo J, Exner M, Fricker C, Glasmacher A, editors. Heterotrophic counts and drinking-water safety: the significance of HPCs for water quality and human health. London, UK: IWA publishing; 2003.*
[8] *National Primary Drinking Water Regulations. EPA. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#one. Published February 14, 2020.*
[9] *Huang CT, Yu FP, McFeters GA, Stewart PS. Nonuniform spatial patterns of respiratory activity within biofilms during disinfection. Appl Environ Microbiol. 1995;61(6):2252-2256. doi:10.1128/AEM.61.6.2252-2256. Published 1995.*
[10] *Zingg W, Pittet D. Electronic-Eye Faucets—Curse or Blessing? Infection Control & Hospital Epidemiology. 2012;33(3):241-242. doi:10.1086/664494. Published 2012.*



Bacterial concentration of distilled water after a 48-hour incubation period

For feedstock we used both chlorinated municipal tap water (MTW), supplied by the city of Hayward in California, and chlorine free bottled water (CFW). Periodic monitoring of the MTW using an Extech CL200 Cl meter periodically calibrated against 1 ppm Cl standards showed that the free chlorine levels consistently read between 3.6 and 4.0 ppm, near the high end of the allowable standard EPA levels of 4 ppm.[11] This should represent some of the microbially safest US tap water available, so the following MTW results are a best case scenario for bacterial exposure from a filter pitcher. The CFW leg of the experiment is applicable to the more than 42 million Americans that use domestic well water as well as users in countries where chlorination, or similar technologies, is not widely used (i.e., Holland, Germany and Switzerland)[12,13,14,15], where the quality of municipal water treatment is suspect.[16]

In this study we did not investigate the worst case scenario where the input water is contaminated at the source (i.e., Beijing municipal water)[17]. Another source of microbial contamination is by the delivery plumbing itself which will be addressed in a follow up study.

IV. Results

Figs. 1 and 2 summarize how the measured bacterial counts evolve over time. The x-axes give the fraction of the manufacturer's rated filter life. And the y-axes show the measured colony forming units (CFU) per ml of filtered water. To put these measured bacterial levels into context, the dashed horizontal line shows the guideline for potable water as recommended by the US EPA guidelines for figure 1 and the CDC guidelines for figure 2.

Bacteria were found in all the experimental legs, starting with the first measurement point at 25 liters. Very high levels were detected as early as 35 liters (9 gallons) of total filtered volume (~ 2 weeks). In all cases the curves show a slow steady increase in contamination load until a tipping point is reached and the microbial loads rapidly increase to extremely high levels.

---

[11] *Office of Water. Drinking Water Standards and Health Advisories. https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf. March 2018.*

[12] *van der Kooij DWJJ, van der Wielen PWJJ. Microbial Growth in Drinking-Water Supplies Problems, Causes, Control and Research Needs. London: IWA Publ.; Published 2013.*

[13] *Rosario-Ortiz F, Rose J, Speight V, von Gunten U, Schnoor J. How do you like your tap water?. Science. 2016;351(6276):912-914. doi:10.1126/science.aaf0953*

[14] *Smeets PWMH, Medema GJ, van Dijk JC. The Dutch secret: how to provide safe drinking water without chlorine in the Netherlands. Published 2009.*

[15] *Rosario-Ortiz F, Speight V. Can drinking water be delivered without disinfectants like chlorine and still be safe? The Conversation. http://theconversation.com/can-drinking-water-be-delivered-without-disinfectants-like-chlorine-and-still-be-safe-55476. Published March 7, 2016.*

[16] *Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. file:///Users/elainetu/Downloads/JMP-2017-report-final%20(1).pdf. 2017.*

[17] *Ye B, Yang L, Li Y, Wang W, Li H. Water Sources and Their Protection from the Impact of Microbial Contamination in Rural Areas of Beijing, China. International Journal of Environmental Research and Public Health. 2013; 10(3):879-891. Published 2013*

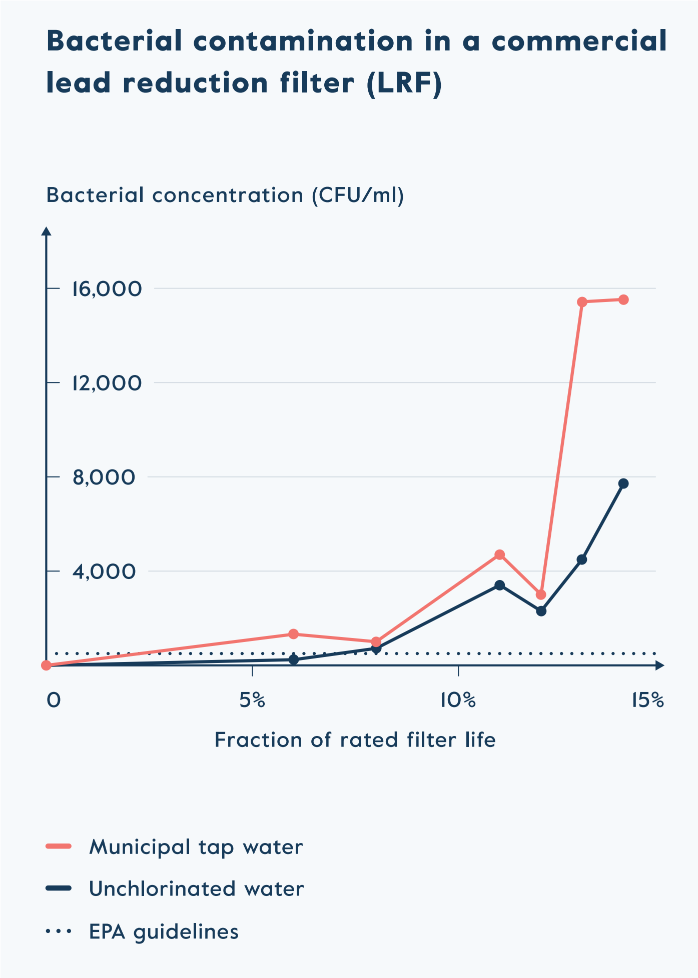


Figure 1 Bacterial contamination in a commercial lead reduction filter

The results for the LRF are shown in Fig. 1 for both chlorinated (black curve) and unchlorinated (blue curve) water. Bacterial contamination was found almost immediately and rapidly grew out of control after using the filters for only a fraction of their rated 120 gallon (454 liter) lifetime. More importantly chlorination of the input water had a minimal impact on the rate of bacterial colonization of the filter. At less than 15% of the rated filter lifetime the bacterial loads are extremely high. We suspended testing at this point because the filter flow rates had dropped to unusably low levels.

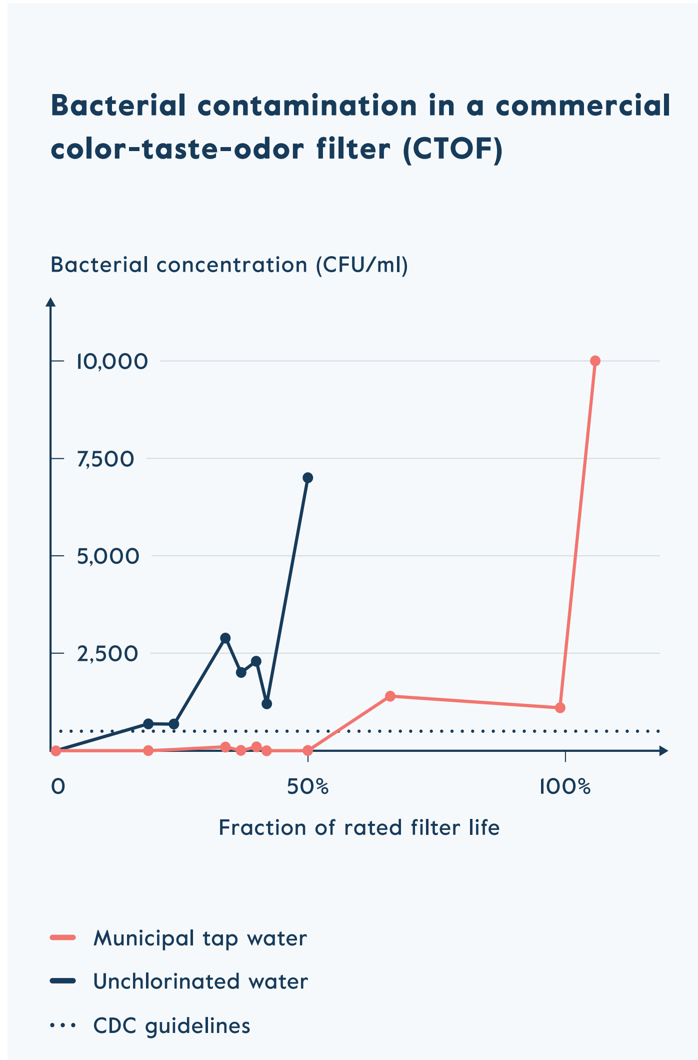


Figure 2 Bacterial Contamination in a commercial color-taste-odor filter

The CTOF results are shown in Fig. 2 above. For CFW (blue curve) bacteria are present in the very first sample taken at only 20% of the filter's rated lifetime of 40 gallons (151 liters). Worse the bacterial load appears to be growing unchecked after only 50% of the rated filter life, and testing was suspended. For this case changing the filter on the manufacturer's recommended schedule does not protect users from bacterial exposure. It should be emphasized that clean distilled water was used for these tests so the environment in the filter medium is providing both the source of bacteria and the nutrients needed for rapid colonization. Though it should be noted that microbial contamination has been detected in freshly manufactured, unused filters as well[18]. In contrast, for MTW (black curve) very little to no bacteria is initially detected but at just past 60% of the filter's rate lifetime the bacteria levels also began to rapidly increase above the recommended levels of 500 CFU/ml. It shows that while chlorinated water can initially help to control bacterial colonization of the filter, eventually large quantities of microbes will establish themselves and subsequently contaminate the users' drinking water. The result also clearly demonstrates that while on-schedule filter changes help to suppress biological contamination in chlorinated water, this alone is not enough to cure the problem.

V. Conclusion

We observed rapid bacterial colonization of two types of commercial filters, which subsequently shed bacteria into drinking water. One filter design shed unacceptably high levels of bacteria after less than 10% of its manufacturer's rated lifetime, indicating significant deficiencies in its design. Chlorination of the feedstock water did not significantly affect the rate of microbial colonization of this filter design. A second commercial filter shed bacteria at the first test point when fed with unchlorinated water. Chlorinated feedstock water with unchlorinated water. Chlorinated feedstock water delayed the onset of bacterial colonization but did not eliminate it.

While countertop water filter pitchers are effective at improving taste and can also improve certain other aspects of water quality, they are at risk for microbial contamination. This is an unavoidable consequence of chlorine removal which provides residual antimicrobial protection for drinking water. The shortcomings of existing household countertop water filters leaves the consumer with the unacceptable dilemma of choosing between consuming the chemicals present in their unfiltered water, or exposing their families to the risk of microbial contamination. Consequently, additional measures are required to minimize exposure to potentially pathogenic microbes.

[18] *Daschner et al. Microbiological contamination of drinking water in a commercial household water filter system. Eur. J. Clin. Microbiol. Infect. Dis.15(3), 233–237. Published 2016*