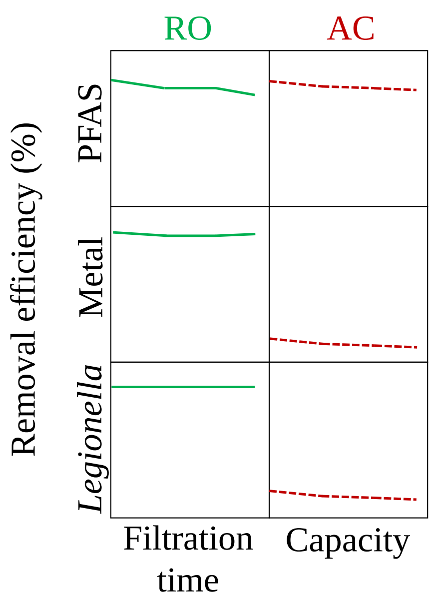
Emerging contaminant removal and microbial growth in membrane filtration and activated carbon point-of-use technologies



Executive Summary

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Reverse osmosis (RO) systems and activated carbon (AC) systems are common point-of-use (POU) water filtration systems. They are used to remove contaminants from drinking water, including trace-level emerging contaminants, as the last barrier to protect human health before consumption.

Per- and poly-fluoroalkyl substances (PFAS) have recently gained attention as emerging contaminants due to their high persistence and potential health risks [1]. Studies have shown that drinking water may act as a significant exposure route to trace level PFAS and contribute to the accumulation of PFAS in human bodies [2, 3]. Epidemiological studies suggest potential links between PFAS exposure and numerous adverse health problems, including testicular and kidney cancer, thyroid disease, and metabolic disorders [4]. It is worth noting as well that short-chain PFAS have been frequently used to replace conventional long-chain PFAS in manufacturing processes.

Trace levels of manganese (Mn) and uranium (U) are often detected in drinking water. Mn may pose health risks on neurobehavioral impairment [5], idiopathic Parkinson's disease [6], kidney stones [7], metabolic syndrome [8], and interruption of kidney function and glucose metabolism. U in drinking water has been linked to leukemia, nephrotoxic effects, and tumors and liver diseases [9]. *Legionella* bacteria have been widely detected and pose severe health risks to humans. The reported annual rate of legionellosis in the US increased significantly in recent years and Legionnaires' disease is fatal in 10% of infected patients [10].

However, only limited studies have been done to evaluate emerging contaminant reduction by POU technologies. The overall research objective of this study was to systematically evaluate removal of select PFAS chemicals, metals, and *Legionella* by POU systems. Three unique RO systems and three unique AC systems were tested in this study.

PFAS mixtures of perfluorooctanesulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), and perfluorobutane sulfonic acid (PFBS) in two different concentrations (1 µg/L and 10 µg/L) were spiked into tap water. Solid phase extraction coupled with liquid chromatography tandem mass spectrometry (SPE-LC/MS/MS) was used to quantify PFAS concentrations. Duplicate samples of PFAS were collected and measured. Mn and U were spiked into tap water and their removal efficiencies were quantified by inductively coupled plasma (ICP). Removal efficiencies of background calcium (Ca), magnesium (Mg), iron (Fe), and copper (Cu) were also quantified. Triplicate samples of metals were collected and measured. AC filters were tested to 200% of their designed treatment capacities (1,000 gallons for AC-1, 600 gallons for AC-2, 400 gallons for AC-3) and RO membranes with recovery of 19.3% were tested for three weeks.

The PFAS data indicate they were effectively removed by both RO membranes and AC filters, where average removal efficiencies were greater than 90% in all POU devices tested. Among the three evaluated PFAS with different chain-lengths (PFOS: 8 carbons, PFHxS: 6 carbons, PFBS: 4 carbons), higher removal efficiencies were observed in long-chain PFAS (carbon chain-length ≥ 6), while relatively low removal efficiencies were observed in PFBS removal. These results suggest that the tested POU technologies are generally effective to remove PFAS, but short-chain PFBS may not be consistently removed.

All tested metals were effectively removed by RO membranes. AC filters in this study were ineffective at reducing Ca, Mg, Mn, and U. While not designed to remove them, it was observed that the tested AC filters partially reduced dissolved Fe and effectively reduced trace level Cu. Additional additives may be added to AC filters to remove metals.

Legionella is a pathogen detected in drinking water and removal of different concentrations of *Legionella* by POU devices was tested. The results showed that *Legionella* was effectively removed by RO membranes with removal efficiencies being 100%, while AC filters did not remove *Legionella* effectively and the removal efficiencies were all below 31.3%.

Assimilable organic carbon (AOC) is widely detected in drinking water distribution systems and has often been used as an indicator of microbial growth. Undesired microbial

growth in POU systems may reduce treatment efficiencies of POU systems, impair flow rates, and increase maintenance costs. Therefore, a second objective of the study was to investigate the removal of AOC to determine how microbial growth potential may be affected in POU systems. The results showed that AOC was variably, but effectively, removed by all tested RO membranes and AC filters. The observed variability of AOC removal efficiencies may be attributed to the heterogenicity of biofilm and microbial growth in POU systems.

Fouling, which is surface deposition of particles, colloids, macromolecules, salts, microbes, etc., may significantly increase operation costs of membrane systems by increasing the frequency of prefilter and membrane replacement, and is one of the most challenging issues that impact performance of POU systems. Fouling development was investigated in both RO membranes and AC filters. It was found that an AOC level of 100 µg/L promoted fouling in both RO membranes and AC filters, and microbial growth was significant in the AC filters by the time they reached their 200% treatment capacity. PFAS removal efficiencies were not correlated with foulants or bacterial concentrations in AC filters, except that PFOS removal efficiency was significantly correlated with bacterial concentration, which may be attributed to the increased cell hydrophobicity in mature biofilm on AC-1 filter. Except for Cu, the metals tested in this study were not affected by fouling development in AC filters.

The new knowledge generated from this study can help improve our understanding of emerging contaminant removal by POU technologies. It can help mitigate human health risks by guiding the development of better strategies for the design and operation of POU systems to remove emerging contaminants in drinking water.

Further work can evaluate how physical and chemical properties of emerging contaminants may affect their removal efficiencies. For example, POU mechanistic studies can evaluate whether solubility is a better predictor of reduction as compared to carbon chain length for PFAS removal. It would also be useful to evaluate if microbial growth affects removal of different emerging contaminants.

Reference

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