CLEAN WATER

Drink safely with biomimetic nanotechnology

An artificial nanostructure inspired by the sea anemone can be used for efficient removal of a wide range of water contaminants

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The world reached a landmark in 2010 when the global Millennium Development Goal target for use of improved drinking water sources was met ahead of schedule. In 2015, 91% of the global population used an improved water source, though this accomplishment still left over 660 million people without such access¹. The Sustainable Development Goal 6 “Ensure availability and sustainable management of water and sanitation for all” raised the bar from “improved water sources” to “safely managed drinking water services”, including an explicit requirement that drinking water be free from contamination².

Human exposure to contaminants in drinking water is affected by the quality of source water and how it is treated as well as (re)contamination that can occur during conveyance or in the household^{3,4}. The quality of source waters varies widely, with surface waters generally being more vulnerable to contamination by disease-causing microorganisms (pathogens), groundwater more often having elevated concentrations of naturally-occurring substances derived from geologic materials (such as arsenic and fluoride) and both being locally affected by industrial contamination associated with production, storage, disposal or accidents. In regions with scarce renewable freshwater resources, saline or brackish water and even treated wastewater effluents may also be further treated to produce drinking water. The enormous variety of potential contaminants in drinking water, particularly those subject to the U.S. National Primary Drinking Water Regulations⁵ (see Fig. 1), poses a daunting challenge for safe water supply.

The variability in the quality of source waters used for drinking water supply is reflected in the application of different types of water treatment technologies³. Often, treatment technologies are implemented in series as existing water treatment plants are upgraded to meet new water quality requirements. Serial implementation of technologies can also be necessary if a broadly-effective treatment process (such as membrane-based reverse osmosis) requires pre-treatment to maintain performance.

Now writing in *Nature Nanotechnology*, Liu et al.⁶ offer an alternative of radical simplicity that could allow low- and middle-income countries to leapfrog the implementation of multiple technologies for drinking water treatment. Eventual replacement of existing, installed technologies could also simplify operations even where high-quality drinking water is currently provided.

The approach taken by Liu et al. mimics the feeding strategy of actinia or sea anemone (Fig. 2), which extends its tentacles to ensnare its prey. Their actinia-like micellar nanocoagulant (AMC) has an aliphatic core surrounded by an alumino-silicate shell. When used in water treatment, the shell hydrolyzes, forming a floc that enmeshes particulate contaminants. This also exposes the aliphatic tentacles of the core, which can adsorb dissolved organic and inorganic contaminants. Thus, AMC can potentially serve to remove a broad spectrum of contaminants.

The actual use of AMC in water treatment will depend not only on its effectiveness but also on its feasibility from the perspectives of production, storage and handling. AMC synthesis is based on the hydrolysis of a commercially-available chemical to form a quaternary ammonium compound with an aliphatic tail and silanol head group. After condensation of the silanol with aluminum chloride, the product self-assembles into micelles (i.e., AMC). At pH < 4, the AMC suspension is stable for an extended period that would allow for storage, shipping and handling.

The performance of AMC was tested using a very challenging matrix (effluent from secondary wastewater treatment). Application of AMC showed excellent performance (>90% removal) not only for typical water quality parameters, such as turbidity and nitrate, but also for organic micropollutants and pharmaceuticals. The performance with nitrate is particularly notable since this

contaminant is not removed by conventional coagulants and requires a targeted treatment process (most commonly ion exchange)³. Although the reported 94% removal of nitrate by AMC brings the nitrate concentration down to a value that is uncomfortably close to the drinking water standard (0.96 vs. 1 mg/L as N), the secondary sewage effluent used to test the AMC performance is a much more challenging matrix than would be encountered in actual drinking water treatment.

Confidence in observed AMC performance and in predictions of performance under varying conditions can be gained through the understanding of the mechanistic basis of contaminant removal. Liu et al. use a combination of methods to characterize AMC and to explain its coagulation behavior and performance. Molecular dynamic (MD) simulations indicated electrostatic interactions of the nitrate anion with the AMC nitrogen atoms in contrast to the hydrophobic interactions of the analgesic diclofenac with AMC carbon chains. The aggregation of fluorescent dye molecules and their uptake into AMC flocs were also directly observed using fluorescence microscopy.

The further development of AMC for use in water treatment will expand the portfolio of treatment options to address a wide spectrum of contaminants. The test application of AMC to secondary wastewater effluent is also a reminder that the needs and opportunities for water reuse are blurring the distinction between source water and wastewater⁷. Decentralized recycling and reuse offer the possibility of dramatically decreasing the demand for water delivery to the household; recovery and treatment of lightly-contaminated greywater for household reuse would have the potential to reduce the average daily global demand of 142 L per person by up to 65%⁸.

The AMC broad-spectrum, single-step approach challenges the historical development of multiple treatment technologies targeting specific classes of contaminants. While this approach may eventually have a broad utility, we should be wary of succumbing to the lure of a silver bullet or one-size-fits-all solution. Despite long-distance conveyance and global water policies, issues of water supply and treatment have a fundamentally-local character and workable solutions must reflect local needs, contexts and opportunities, including opportunities to recover water, nutrients and energy from wastewater⁸. AMC has the potential to be a valuable addition to the portfolio of options for

safe water supply that will help the world to meet the challenge posed by the Sustainability Development Goal 6.

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Suggested graphics

Figure 1. First 7 entries from the USEPA list of 88 contaminants subject to the National Primary Drinking Water Regulations and the accompanying legend for the types of contaminants ⁵.

Contaminant	MCL or TT ⁶ (mg/L) ¹	Potential health effects from long-term ⁶ exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L) ²
Acrylamide	TT ⁶	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment	zero
Alachlor	0.002	Eye, liver, kidney, or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero
Alpha/photon emitters	15 picocuries per liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero
Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
Arsenic	0.010	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes	0
Asbestos (fibers >10 micrometers)	7 million fibers per liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003

LEGEND	DISINFECTANT	DISINFECTION BYPRODUCT	INORGANIC CHEMICAL	MICROORGANISM	ORGANIC CHEMICAL	RADIONUCLIDES
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Figure 2. Closed and open configurations of the sea anemone (Actinia). Source: <https://www.colourbox.com/vector/opened-and-close-sea-anemone-old-engraved-illustration-sea-anemones-are-a-group-of-water-dwelling-predatory-animals-of-the-order-actiniaria-vector-4840000>

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