Membranes Technologies and Contaminants of Emerging Concern

OVERVIEW

With increasing frequency, research is documenting that many inorganic, organic, and microbial constituents—not historically considered as contaminants—are present in the environment at low quantities on a global scale. These "contaminants of emerging concern" are commonly derived from municipal, agricultural, and industrial sources, yet are often dispersed to the environment via domestic and commercial pathways. Chemicals of emerging concern are influencing the selection of current and future treatment technologies utilized by the drinking water community, and membrane processes represent a tool for dealing with these contaminant challenges.

WHAT ARE CHEMICALS OR CONTAMINANTS OF EMERGING CONCERN?

Advanced analytical capabilities have allowed scientists to identify chemicals in the environment at extremely low concentrations. Contaminants of emerging concern (CECs) are those chemicals that, recently, have been shown to occur widely in water resources and are identified as having the potential for adverse risk to public health or the environment. CECs are used daily in homes and gardens as well as in agriculture and other industries and include products such as detergents, fragrances, personal care products, prescription and non-prescription drugs, disinfectants and disinfection by-products (DBPs), pesticides, herbicides and nanomaterials.

One study conducted by the U.S. Geological Survey as part of the Toxic Substances Hydrology Program reported detections of 82 chemicals in 80 percent of 139 streams and waterways tested between 1999 and 2000. The most common chemical groups observed were steroids, antibiotics, nonprescription drugs, caffeine, and insect repellent. Potential sources of these contaminants are wastewater discharges, agricultural and industrial run-off, industrial air emissions, and discharge from individual septic systems. **Table 1** presents a partial listing of CECs found in wastewater effluent and the aquatic environment.

The U.S. Environmental Protection Agency's (EPA) 2016 Contaminant Candidate List (CCL4) included 97 chemicals or chemical groups and 12 microbial candidates, among which are chemicals used in commerce, pesticides, biological toxins, DBPs, pharmaceuticals, and waterborne pathogens. *[Note: As of 2021, EPA is working on a draft version of CCL5].* While the occurrence of CECs correlates with a variety of ecological impacts, links between CECs and the environment and a cause-and-effect relationship have not been directly established. However, these emerging chemical contaminants—industrial solvent stabilizers (1,4-dioxane), fuel oxygenates, disinfection byproducts, pharmaceuticals, personal care products, pesticides and herbicides (1,2,3-trichloropropane), algal toxins, emerging pathogens, phthalates, and other persistent compounds used in common products such as flame retardants, food packaging and water-resistant fabrics (e.g., per- and polyfluoroalkyl substances)—illustrate many technical and institutional challenges.

TABLE 1: Emerging Contaminants in Wastewater Effluent and the Aquatic Environment

EMERGING CONTAMINANT CLASS	Examples
Pharmaceuticals (antibiotics/drugs)	Ibuprofen, Codeine, Caffeine, Diazepam, Acetylsalicylic acid, Carbamazepine, Diclofenac, Fenoprofen
Veterinary and Human Antibiotics	Trimethoprim Erythromycin Lincomycin Sulfamethoxazole
Hormones	17-b-estradiol 17-a-ethynylestradiol Estriol Estrone 4-nonylphenol
Flame Retardants	Polybromodiphenylethers Tri(2-chloroethyl)phosphate
Per- and Polyfluoroalkyl Substances (PFAS)	Perfluorooctanesulfonic Acid (PFOS) Perfluorooctanoic Acid (PFOA)
Personal Care Products (polycyclic musks)	Galaxolide Parabens Siloxanes
Industrial Solvents	1,4-dioxane

MEMBRANE PROCESSES CAN ADDRESS CONTAMINANTS OF EMERGING CONCERN

Both regulatory requirements and public concern are driving the need to improve contaminant removal for both wastewater discharges and drinking water systems. Conventional wastewater treatment varies greatly in its ability to eliminate drug or personal care product residues and additional treatment may be required at the effluent discharge location. Likewise, drinking water providers are under increased pressure to better address contaminants, especially for industrial chemicals with limited available research data, prior to sending to customers in the distribution system. Membranes are effective for the treatment of organic precursor matter, and pilot studies show that they are also effective for meeting removal targets greater than 90 percent for many contaminants of emerging concern.

Although there are several mechanisms controlling contaminant removal by membranes, size exclusion is significant and can be used to describe membrane capability. If the contaminant is too large to pass through the membrane pore, then it is removed from permeate or filtrate streams. Contaminants can be categorized simply as microbiological (i.e., pathogens), organic solutes, and inorganic solutes. Pathogens can be further categorized as protozoa, bacteria, and viruses. Organics can be subdivided into DBPs and their total organic carbon (TOC) natural precursors, synthetic organic compounds (SOCs) and volatile organic chemicals (VOCs). Inorganic solutes include such contaminants as total dissolved solids, total hardness, metals, and other inorganic contaminants.

Reverse osmosis (RO) and nanofiltration (NF) are both diffusion and size exclusion-controlled membrane processes. RO and NF processes have the broadest span of treatment capability but require the greatest degree of pretreatment. Ultrafiltration (UF) membranes can achieve greater than six-log removal of all pathogens from drinking water and microfiltration (MF) can achieve greater than six-log removal of protozoa and bacteria. Consequently, membrane processes are ideal for removing turbidity and microbiological contaminants, and they are well suited for treating the majority of drinking water sources in the United States.

Log rejection will increase as flux increases and decrease as recovery increases in diffusion-controlled membrane processes (primarily NF and RO). No change will occur in size exclusion-controlled processes (primarily MF and UF). Pathogen removal by NF or RO is controlled by a size exclusion mechanism, whereas ion removal is diffusion controlled. Removal of organic compounds is achieved through both mechanisms. Diffusion controlled processes have the flexibility of decreasing recovery to produce a higher water quality if more feed water is drawn to meet production needs.

Table 2 presents examples of treatment effectiveness for several specific endocrine disruptors using NF and RO. Membranes have distinct treatment advantages relative to these and other contaminants of emerging concern. RO or NF membranes can remove TOC or other DBP precursors such that free chlorine may be used for disinfection without exceeding the EPA regulated levels within the distribution system. Pressure driven membrane processes can reject five to six logs of viruses, bacteria or cysts, exceeding most—if not all—treatment capabilities of any other single process.

RO or NF membranes can reject small molecular weight pesticides and are used to meet stringent European water quality standards and will likely reject higher molecular weight pharmaceuticals, endocrine disruptors, and algal toxins.

While there are typically no water quality disadvantages to membrane separation, the significant disadvantages are cost and concentrate disposal. Fortunately, costs continue to decrease due to technological innovation, and concentrate disposal is typically a regulatory requirement rather than a technical challenge. Membranes can meet or exceed current and pending water quality regulations. Moreover, some drinking water lifecycle analyses show that the use of membranes for the removal of industrial contaminants in fresh (low chloride levels), raw water sources can be more cost-effective than other advanced treatment processes, especially at higher target removal rates.

TABLE 2: NF and RO Treatment Effectiveness for Specific CECs

CHEMICAL	TYPE	REMOVAL (%) NF	REMOVAL (%) RO
Acetaminophen	Analgesics	30	>90
Ibuprofen		98	>98
Naproxen		23	>95
Trimethoprim	AntibioticMuscle Relaxant Steroid Steroid	22	90
Diazepam		55	>95
17β – Estradiol (Estrogen)		20	90
Testosterone (Androgen)		60	95
Triclosan	Antimicrobial Insecticide Surfactant	45	>96
DEET		75	>90
Nonylphenol		>99	>99
PFOA and PFOS	Industrial / Manufacturing / Aqueous Film-Forming Foam	>94	>98

EMERGING CONTAMINANT ISSUES WILL CONTINUE TO EVOLVE

Unregulated and emerging chemical contaminants present technical and institutional challenges to environmental and public health professionals and utility systems. Increasingly advanced analytical techniques identify newly detected inorganic, organic, and microbial chemicals in actual or potential sources of drinking water.

As the ability to detect these agents improves, the number of contaminants that need to be evaluated for potential health risks will continue to expand. The discovery of CECs in the environment has outpaced the research community and its ability to study the effects of these contaminants on people and the environment. Consequently, environmental professionals and utility providers must make difficult risk management decisions regarding water resource and water supply management in the face of considerable regulatory uncertainty. The significant cost to build any advanced treatment technology, combined with the uncertain effects and future discovery of additional CECs, often drives the selection of technologies that provide a more comprehensive and higher removal rate of these CECs.

While some technologies do not effectively remove many of these contaminants from water, membrane technologies are effective in removing the broadest range of CECs as either stand-alone processes or when integrated with other advanced technologies. Risk management decisions are now requiring both complex assessments of the vulnerability of a water supply source to unregulated contaminants and also an analysis of the appropriate combination of treatment processes required to meet both current and future water quality concerns arising due to CECs. The lifecycle cost must always be considered in the final analysis.

SOURCES

- The majority of the data for this fact sheet were taken from a publication by Dr. Steve Duranceau, a past president of AMTA and founding member of SEDA and SWMOA. Additional information was taken from USEPA websites (*https://www.epa.gov/ccl/chemical-contaminants-ccl-4* and *https://www.epa.gov/ccl/basic-information-ccl-and-regulatory-determination*) and the April 2018 final report for the Brunswick County Advanced Treatment Options for the Northwest Water Treatment Plant prepared by CDM Smith (*http://www.brunswickcountync.gov/genx/*) and associated ongoing pilot test data.
- Andaluri, G. et al. "Pharmaceutical Chemical Contaminants in Surface Waters and their Aqueous Destruction Using Ultrasound." AWWA Annual Conference, Toronto, Ontario, Canada; June 24-28, 2007.
- B. Halford. "Side Effects." Chemical and Engineering News (C&EN). Vol 86., No. 8, February 25, 2008 p. 13-17.
- Cummings, L. et al. "Recommendation on Perfluorinated Compound Treatment Options for Drinking Water." New Jersey Drinking Water Quality Institute Treatment Subcommittee. June 2015. www.nj.gov/dep/watersupply/pdf/pfna-pfc-treatment.pdf.
- EPA/625/R-00/015. "Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes." March 2001. Washington DC.
- George, E and Y. Li. "Chemicals of Emerging Concern in Ground & Surface Waters." NEHA Annual Educational Conference, Anchorage, Alaska, May 11, 2004.
- Higgins, C.J. and S.J. Duranceau. "Modeling of Mass Transfer and Endocrine Disrupting Compound Removal in a Nanofiltration Membrane Process Modified for Acid Pretreatment Conditions." Proceedings of the AMTA-AWWA 2018 Membrane Technology Conference & Exposition, March 12-16, 2018, at the West Palm Beach Convention Center, FL.
- J. Oppenheimer and R. Stephenson. "Chemicals of Emerging Concern: Insights to the Most Effective EDC and PPCP Treatment Strategies." Opflow, Vol. 34, No. 5, May 2008.
- K.A. Reynolds. "Concern of Pharmaceuticals in Drinking Water." Water Conditioning and Purification, Vol. 50, No. 4, April 2008.
- Pontius, F. USEPA EDC Workshop, Jan. 29-30, 2002; Cincinnati, OH.
- Snyder, S., et al. "Removal of EDCs and Pharmaceuticals in Drinking and Reuse Treatment Processes." Denver, CO: AWWA Research Foundation, 2007.
- Snyder, S., et al. "State of Knowledge of Endocrine Disruptors and Pharmaceuticals in Drinking Water." Denver, CO: AWWA Research Foundation, 2008.

AMTA
American Membrane Technology Association

FOR MORE INFORMATION:
American Membrane Technology Association (AMTA)
PO Box 14918
Tallahassee, FL 32317
Phone: (772) 469-6797
Email: custsrv@amtaorg.com
www.amtaorg.com

@AmericanMembraneTechnologyAssociation

@amtaorg

- Steinele-Darling, E and M. Reinhard. "Nanofiltration for trace organic contaminant removal: structure, solution, and membrane fouling effects on the rejection of perfluorochemicals." Environmental Science & Technology, Vol. 42, No. 14 pages 5292-5297, June 10, 2008.
- Tabe, et al. "Occurrence of PPCPs and EDCs in Detroit River and Their Removal Using Ozone Processes." AWWA Annual Conference, Toronto, Ontario, Canada; June 24-28, 2007.
- Thompson, J. et al. "Removal of PFOS, PFOA and other perfluoroalkyl acids at water reclamation plants in South East Queensland Australia." Chemospshere. Vol. 82, No. 1, January 2011, pages 9-17.