Membrane Treatment Processes & their Ability to Address Emergent Pollutants of Concern

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For several years, the water and wastewater industry has been cognizant of the environmental impact of discharged wastewater effluents containing high levels of nitrogen and phosphorus; therefore, several wastewater treatment facility processes are designed to remove nitrogen and phosphorus to the lowest of levels. Recently, however, industry professionals have been questioning and researching what other pollutants may exist in our wastewater effluents.

Tiny amounts of everyday products ranging from antibiotics to hormones to detergents survive in our wastewater, even after it is treated and disinfected. The effluent from these wastewater treatment facilities is typically discharged to rivers, sprayed on agricultural and public properties, or injected underground to replenish our drinking-water supplies.

Contamination of raw-water supply sources from pharmaceuticals and personal-care byproducts is an emerging challenge for the water treatment industry. Today the states of California and Florida are leading the research on the effects of these human byproducts on humans, wildlife, and the environment.

These pollutants find their way into water supplies as treated wastewater effluent or surface-water runoff through a variety of natural pathways. Very few wastewater treatment facilities have been designed to specifically reduce or eliminate these byproducts. This also holds true for most water treatment facilities.

Until recently, researchers did not have the means, equipment, or know-how to detect these contaminants, which are commonly categorized as "*Emerging Pollutants of Concern*" (EPOCs) and include endocrine disrupters, in addition to pharmaceuticals, personal-care byproducts, and other substances [6]. Since detection methods have improved and the knowledge of such compounds has spread to the public customer base, utilities must struggle with how to handle these unregulated contaminants.

In the face of limited water-supply sources and increased regulatory limitations, utilities have been investigating alternative sources of water supply, such as surface-water sources and aquifer recharge. During recent years, membrane technologies have emerged as a potential leader in the search for potable water treatment processes that will address EPOCs.

Emerging Pollutants of Concern

Emerging Pollutants of Concern refer to a group of currently unregulated chemicals that have been identified to be potentially harmful to humans and wildlife. These chemicals consist of Endocrine Disrupting Chemicals (EDCs), Hormonally Active Agents (HAAs), Pharmaceutically Active compounds (PhACs), Personal Care Products (PCPs), Disinfection Byproducts (such as NDMA), and Organic Wastewater Contaminants (OWCs).

EDCs are derived from man-made chemicals and appear to interfere with the normal functioning of human and wildlife endocrine systems. Pesticides are a good example of EDCs found in drinking-water supplies.

HAAs may include estrogen, steroids, birth control, and other hormonal adjusting medications. PhACs include prescribed and non-prescribed medications that make their way to water supplies as unused drugs through direct disposal to landfills, excretion to the wastewater collection system, or direct disposal to the wastewater system.

PCPs include chemical agents found in cosmetics, fragrances, lotions, deodorants, etc., that make their way to water supplies in the same manner as PhACs.

There is limited information available on the fate and transport of EPOCs in the environment, but recent studies performed by governmental agencies such as the United States Geological Survey show the existence of OWCs in a majority of streams sampled in the United States [6]. Other current research has found landfills and wastewater treatment facility effluents contributing to the existence of other EPOCs in the environment and our drinking-water supplies.

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Overview of Membrane Processes

Membrane processes that have applications in drinking-water treatment include reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) and electrodialysis reversal (EDR). Table 1 lists the regulated solutes controlled by membrane processes. EDR is not represented in this table.

Combinations of membrane processes with other membrane or traditional treatment processes are known as integrated membrane systems. Accepted examples of these systems are the coupling of MF and NF processes or a combination of coagulation, sedimentation, and filtration with an NF process.

MF and UF are pressure-driven filtra-

Continued on page 42

Table 1: Characteristics of Membrane Processes

Process	Mechanism	Exclusion	Regulated Solutes		
			Pathogens	Organics	Inorganics
RO	S, D	0.0001 µ	C, B, V	DBPs, SOCs	All
NF	S, D	0.001 µ	C, B, V	DBPs, SOCs	All
UF	S	0.001 µ	C, B, V	None	None
MF	S	0.01 µ	C, B	None	None

Mechanism: S=sieving, D=diffusion
Pathogens: C=cysts, B=bacteria, V=viruses
Organics: DBPs=disinfection by-product precursors, SOCs=Synthetic Organic Compounds
Source: (8)

Continued from page 41

tion processes that utilize hollow-fiber membranes capable of separating both insoluble and soluble materials from the treated water. Hollow-fiber membranes are either “inside-out” cross-flow membranes, or “outside-in” transverse-flow membranes.

The applied pressures utilized with MF/UF processes (2 to 90 psi) are much less than feed pressures for NF (70 to 150 psi) or RO processes (140 to 1,000 psi). MF and UF remove particles, turbidity, bacteria, and protozoa. In addition, UF removes some viruses.

NF and RO remove turbidity, color, pesticides, natural organic matter (NOM), and hardness. In addition, RO processes remove salinity [9].

The specific application of membrane processes to drinking-water applications is shown in simplified format in Table 2.

UF has been shown to be very effective for particle and turbidity removal [8]. Turbidity can be lowered to below 0.05 NTU on a consistent basis for a variable feed-water quality.

Unlike MF, UF is capable of removing many viruses—as well as coliforms, bacteria, viruses, and cysts. Similarly to MF, however, UF does not effectively remove disinfection byproducts or other dissolved substances from a water supply unless additional treatment, such as powdered activated carbon addition, is provided [8].

UF and MF membranes cover a wide range of molecular weight cut-offs and pore sizes. Materials of construction for MF and UF membranes continue to improve as a result of recent advances in technology [8]. MF and UF modules can vary in terms of module dimensions, membrane material, pore size, capillary diameter, position (horizontal vs. vertical), inside-out and outside-in membranes, and air scour/chemical backpulsing systems.

RO and NF remove a variety of contaminants; therefore, this technology has emerged as a leader for affordable multi-contaminant removal. The membranes require a high pressure feed to achieve reverse osmosis.

Based on the maturity of these two processes in the water-treatment industry, membrane treatment skids for RO and NF are typically provided in standard components. The membrane skids are typically two-stage treatment systems, provided with adequate pretreatment to protect the membranes. Membrane elements are typically 8-inch by 40-inch, spiral-wound elements. For surface-water applications, MF/UF is typically used as a pretreatment process to the RO/NF system.

As mentioned previously, typical applications for NF include reduction of hardness and organics, while RO is used for reduction of the same constituents listed for NF, as well as salinity, chlorides, total dissolved solids, and EPOCs.

Membrane Applications for EPOCs

There are two regulatory approaches available for the removal of EPOCs from public drinking-water sources. The first approach is to treat the source that is contributing the contaminant, which would include advanced treatment of the wastewater effluent, landfill leachate, and/or agricultural runoff. The second approach is to incorporate advanced treatment facilities at public drinking-water treatment plants.

The most promising technology for both approaches is the use of NF and RO technologies. MF/UF technologies show promise in combination with other treatment processes or in integrated membrane systems. The use of MF/UF in combination with granular activated carbon has shown potential in the removal of NDMA.

In most membrane surface-water applications or secondary-effluent applications, MF/UF is typically utilized as a pretreatment technology upstream of the RO process equipment. Research has shown that RO and to some extent, NF, have successfully removed greater than 90 percent of certain EPOCs such as antibiotics, pharmaceuticals, hormones, and industrial chemicals [10].

Even RO/NF processes have been more successful with the addition of subsequent treatment processes. Research has shown that the use of ultraviolet disinfection in combination with hydrogen peroxide, known as an advanced oxidation process, shows increased removal of EDCs, PhACs, and NDMA. Most data to date is a product of pilot or bench-scale testing, and perhaps even speculative; therefore, full-scale EPOCs data at large municipal drinking-water facilities is limited, if not non-existent.

Summary & Conclusions

There are numerous challenges associated with monitoring, regulating, and removing EPOCs. Treatment technologies such as membrane processes that are truly capable of addressing EPOCs may be cost-prohibitive to utilities otherwise not requiring such high levels of treatment; therefore, regulatory agencies must establish well-founded risk assessments and reliable analytical techniques and standards so that regulations are able to provide a balance between public health and affordable solutions through the Safe Drinking Water Act [6].

Current U.S. Environmental Protection Agency legislation associated with EDCs includes the *Food Quality Protection Act of 1996* and the SDWA Amendments of 1996. Currently the agency is funding risk management research areas for EDC sources and

Table 2
Summary of Membrane Process Applications for Drinking-Water Regulations

US Regulation/Rule	Membrane Process			
	RO	NF	UF	MF
SWTR/ESWTR	Yes	Yes	yes	yes
TCR	yes	yes	yes	yes
LCR	Yes	Yes	no	no
IOC	Yes	Yes	no	no
SOC	Yes	Yes	yes	yes
Radionuclides	yes (-Rn)	yes (-Rn)	no	no
DBPR	Yes	Yes	no	no
GWDR	yes	yes	yes	yes
Arsenic	Yes	Yes	no	no
Sulfates	Yes	Yes	no	no

SWTR -Surface Water Treatment Rule
ESWTR -Enhanced Surface Water Treatment Rule
TCR -Coliform Rule
LCR -Lead and Copper Rule
IOC -Inorganic Rule (Phases I, II, IIA, V)
SOC -Synthetic Organic Chemicals (Base Neutrals and Extractables)
DBPR -Disinfection By-Products Rule
GWDR -Groundwater Disinfection Rule
Source: (8)

EDC reservoirs. Research includes identifying analytical methods to identify and quantify target compounds and to conduct bench-scale treatment evaluations of various drinking-water treatment technologies. The U.S. Geological Survey continues to do sampling and monitoring for EPOCs in surface waters throughout United States.

Until recently, such drinking-water concerns were not given much consideration in the state of Florida, based on its heavy reliance on groundwater supply sources, but the increased use of chloramines, the increased number of implemented reclamation and reuse programs, and the eventual progression to surface-water sources as alternative water supplies will force Florida to take a closer look at EPOCs, their fate and transport in the environment, and the feasible treatment technologies that can address such contaminants.

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