

## **Appendix 4-1**

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# **Annotated Bibliography on Technologies to Remove Total Organic Carbon, Endocrine Disruptors, and Pharmaceuticals and Personal Care Products**

# **TECHNOLOGIES TO REMOVE TOTAL ORGANIC CARBON, ENDOCRINE DISRUPTORS, AND PHARMACEUTICALS AND PERSONAL CARE PRODUCTS**

## **ANNOTTATED BIBLIOGRAPHY**

1. Adham, Samer, William Pearce, James DeCarolis, Zahir Hiram, and Shane Snyder. "Evaluation of RO Membranes to Prevent Passage of EDC and PPCP." 2006 AWWA Conference & Exposition, San Antonio, TX.

Presents an evaluation of an advanced water treatment (AWT) train including ultrafiltration (UF), reverse osmosis (RO) and ultraviolet light (UV) plus hydrogen peroxide. Concentrations of select endocrine disruptor (EDC) and pharmaceutical and personal care products (PPCP) were presented following each unit process.

2. Angelotti, Robert W., Timothy M. Gallagher, Matthew A. Brooks, and William Kulik. "Use of Granular Activated Carbon as a Treatment Technology for Implementing Indirect Potable Reuse." WateReuse Association Symposium 2005.

Presents information on the Upper Occoquan Sewage Authority (UOSA) water reclamation plant which includes granular activated carbon (GAC) for organics removal. Total chemical oxygen demand (TCOD) and total suspended solids (TSS) data provided.

3. B. Gould, M. Snodgrass, and J. Devine. "Ultrafiltration of Municipal Wastewater Using a Backflushable, Immersed, Spiral Wound Membrane." Proceedings of the WEFTEC 2005 Annual Conference.

Presents turbidity, TSS, chemical oxygen demand (COD) and biological oxygen demand (BOD) data for pilot plants using the SpiraSep ultrafiltration system.

4. Babcock, Roger PhD, Jean-Francois Debroux, PhD., Gregory Arakaki, Westley Chun, June Nakamura, Tieshi Huang, Yingyot Chanthawornsawat, Jing Hu, and Sumon Kanpirom. "Honolulu Membrane Bioreactor Pilot Study." WateReuse Foundation 2003.

Presents total organic carbon (TOC) removal data for a membrane bioreactor (MBR) pilot plant in Honolulu, HI using three different membranes. The pilot was operated at mixed liquor suspended solids (MLSS) concentrations between 6,000 and 16,000 mg/L.

5. Black and Veatch. "SCVWD Advanced Recycled Water Treatment Feasibility Project TM 1 – Background Water Quality and Preliminary ARWT

Technologies Assessment Characterization." Prepared for the Santa Clara Valley Water District, June 2005.

Presents summary water quality and performance data for five AWT facilities: Los Angeles County Sanitation District Reclaimed Water Artificial Recharge Project, Orange County Water District Water Factory 21, the Upper Occoquan Sewage Authority Reservoir Augmentation Project, the City of Scottsdale, Arizona Water Campus, and the Dublin San Ramon Services District Clean Water Revival Treatment Facilities.

6. Bourke, Michael, Stuart Harrison, Bruce Long, and Thomas Lebeau. "MIEX Resin Pretreatment Followed by Microfiltration as an Alternative to Nanofiltration for DBP Precursor Removal."

Summarizes a Magnetic Ion Exchange (MIEX) trial in Sydney, Australia using MIEX treatment upstream of microfiltration. Provides cost comparisons versus nanofiltration.

7. Brown, Richard, David Cornwell, Gary Martinez, Michael Gonzales, Gary Whitten, Michael Bourke, and David Schelbach. "Pre-Treatment with Magnetic Ion Exchange Resin to Reduce TOC, DBP Precursors and Residuals Production." 2006 AWWA Conference & Exposition, San Antonio, TX.

Presentation describing efficacy of MIEX pretreatment for dissolved organic carbon (DOC) removal in drinking water.

8. Conestoga-Rovers & Associates. "Microfiltration Supplemental Technology Demonstration Report - Final Report." FDEP Contract WM 640. May, 1998.

Summarizes results of the Microfiltration Demonstration Project, the initial supplemental technology to be field tested as part of the State of Florida's Everglades Forever Act (EFA)-defined Superior Technology Demonstration Program for reducing phosphorus concentrations in stormwater. Presents feasibility testing of the microfiltration (MF) technology and evaluation of the performance of MF under variable storm water flow rates and influent phosphorous concentrations.

9. Davey, A, P Miller and F Knops. "Australia's Largest Ultrafiltration Reclaimed Water Plant." Water & Wastewater Asia, July/Aug 2005.

Presents water quality data from a 30 megaliter per day (ML/D) UF plant in Melbourne, Australia.

10. Drewes, Jorg, Christopher Bellona, Pei Xu, Gary Amy, Gerald Filteau, and Gregg Oelker. "Comparing Nanofiltration and Reverse Osmosis for Treating Recycled Water." AWWARF 2008.

Compares water quality, feed pressure requirements, operating characteristics, and cost of various nanofiltration (NF) and RO membranes. Presents organic molecule rejection data for NF and RO membranes.

11. Drury, Douglas D., Shane A. Snyder, and Eric C. Wert. "Using Ozone Disinfection for EDC Removal." WEFTEC® 2006.

Presents data on EDC and PPCP destruction by ozone obtained through bench-scale testing.

12. Gleason, Patrick, Davies Mtundu, Mark Elsner, Carlyn Kowalsky, Jose Lopez, and Stacey Feken. "Feasibility of Reclaimed Water for Canal Augmentation to Benefit Water Supplies and Natural Systems in Southeast Florida." 2006 AWWA Conference & Exposition, San Antonio, TX.

Presents anticipated TOC and other water quality parameters following Bardenpho + UV, membrane bioreactor + UV, and RO + UV based on a literature review.

13. HSA Engineers and Scientists. "Pilot Testing of Ultrafiltration For Low Level Phosphorus Removal - Final Report." Prepared for DB Environmental Laboratories, Inc. and South Florida Water Management District, March, 2001.

Presents water quality data for a pilot-scale UF stormwater treatment plant, focusing on nutrient removal.

14. Kikuta, Tomoya and Taro Urase. "Removal of Endocrine Disruptors in Membrane Separation Activated Sludge Process." Tokyo Institute of Technology.

Presents results of a study evaluating removal of 17b-estradiol (E2), estrone (E1), 17a-ethynilestradiol (EE2) and Bisphenol A (BPA) - possible EDCs - in a laboratory membrane separation activated sludge process.

15. Kitpati, Suwanna, Chettiyappan Visvanathan, and Praphan Ariyamethee. "Pilot Scale Investigation of Microfiltration Performance and Reuse Potential for Water and Wastewater."

Reviewed organic fouling potential and TOC concentrations for a pilot-scale MF unit.

16. Krasner, Stuart. "Wastewater-Derived Disinfection Byproducts." 2006 AWWA Conference & Exposition, San Antonio, TX.

- Summarizes water quality (including DOC) from 20 wastewater treatment plants (WWTPs) throughout the United States (US) implementing the following technologies alone or in combination: oxidation ditch, aerated lagoon, trickling filters, activated sludge, nitrification/Denitrification, soil aquifer treatment (SAT), powdered and/or granulated activated carbon, MBR, and RO. Discusses the nature of wastewater effluent organic matter.
17. Landin, Bill S., Karla Kinser, P.E., and Larry Webb. “Advanced Treatment Technologies for Indirect Potable Reuse and Industrial Reclaimed Water Applications.” WateReuse Association Symposium 2005.
- Discusses results of a pilot study conducted for Rio Rancho, NM. The process train consisted of fine screening, secondary treatment, MBR and RO.
18. Lebeque, J., M. Heran, and A. Grasmick. “MBR Functioning Under Steady and Unsteady State Conditions: Impact on Performances and Membrane Fouling Dynamics.” *Desalination* 231 (2008) 209–218.
- Presents MBR performances observed under steady and unsteady state conditions where influent and permeate flow rates were varied. Experiments were performed in a submerged membrane bioreactor with a 50 L working volume.
19. Lee, Jan, P.E. “High-Purity Water from Wastewater: a RARE Opportunity” 2007 AWWA Conference & Exposition, Toronto, CA.
- Presented pilot testing approach and water quality objectives (including TOC) from MF/RO project in northern California.
20. McGuire, Marc, M.K. Davis, S. Liang, C.H. Tate, E.M. Aieta, L.E. Wallace, D.R. Wilkes, J.C. Crittenden, and K. Vaith. “Optimization and Economic Evaluation of Granular Activated Carbon for Organic Removal.” AWWARF 1989.
- The document presents the results of a study to optimize GAC for TOC removal from drinking water, as well as estimated GAC costs for 7 US water agencies.
21. McMillan, Reg and Wayne Hill. “Design and Operation of an Ozone/BAC Water Treatment Plant at Edenhope.” 61st Annual Water Industry Engineers and Operators’ Conference Civic Centre - Shepparton, 2 and 3 September, 1998.
- Provides process information for a water treatment plant in Edenhope, Australia with degraded influent water quality implementing coagulation/filtration, ozone, and GAC.
22. Mosqueda-Jimenez, D.B. and P.M. Huck. “Fouling Analysis of Ultrafiltration and Nanofiltration Membranes.” *Water Practice & Technology* Vol 1 No 4, 2006.

Discusses biofiltration as a sustainable UF and NF pretreatment process to reduce organic fouling. Presents membrane TOC removal data with and without pre-biofiltration.

23. Mourato, D., Ph.D. "Microfiltration and Nanofiltration."

Discusses MF and NF membrane types and typical drinking water applications, including TOC removal. Presents TOC removal efficiencies for coagulation + MF and TOC removal with NF for eight different drinking water systems in the US and Canada.

24. Nam, Seong-Nam, Gary Amy, and Stuart Krasner. "Relating Natural Organic Matter (NOM) and Effluent Organic Matter (EfOM) Properties to Disinfection By-Product (DBP) Formation." 2006 AWWA Conference & Exposition, San Antonio, TX.

Discusses the differences in chemical properties of naturally occurring organic matter and wastewater effluent organic matter.

25. Oppenehimer, Joan, Jay DeCarolis, and Samer Adham. "Integrated Membrane Bioreactor and Reverse Osmosis Systems for Removal of Endocrine Disrupting Compounds, Pharmaceuticals, and Personal Care Products in Water Reuse Applications." WateReuse Association Symposium 2005.

Presents (graphically) concentrations of various EDCs and PPCPs following primary treatment, primary + MBR, and primary + MBR + RO.

26. PB Water. "Project Cost Estimate Peer Review of Microfiltration Supplemental Technology Demonstration Project - Final Report." Prepared for South Florida Water Management District, May 7, 2001.

Presents a review of membrane related costs (capital and O&M) contained in the updated report by HSA Engineers & Scientists, Inc (referenced above). Includes discussion of current MF/UF membrane technology as it relates to capital and O&M costs and a discussion on residuals management.

27. Pearce, William, James DeCarolis, Zahir Hiram, Samer Adham, and Shane Snyder. "Performance Evaluation of an Advanced Water Treatment System for Water Reuse." 2006 AWWA Conference & Exposition, San Antonio, TX.

Presents process information for AWT pilot project treating tertiary effluent with UF, RO, and UV + peroxide. Presents EDC and PPCP removal following each unit process.

28. Rodriguez, Clemencia, Paul Van Buynder, Richard Lugg, Palenque Blair, Brian Devine, Angus Cook, and Philip Weinstein. "Indirect Potable Reuse: A Sustainable Water Supply Alternative." *International Journal of Environmental Research and Public Health*, ISSN 1660-4601.

Provides a high level "state of the art" review of indirect potable reuse with emphasis on membrane treatment processes. Includes an overview of significant indirect potable reuse projects, a description of the epidemiological and toxicological studies evaluating human health impacts, and a summary of operational measures to protect human health.

29. Schäfer, A. I and T.D. Waite. "Removal of Endocrine Disruptors in Advanced Treatment - the Australian Approach." The University of New South Wales Centre for Water and Waste Technology.

Presents preliminary, summary findings from the "Optimised Use of Membrane Hybrid Processes for Water Recycling" Project, an Australian Research Council Project completed in partnership the Queensland Government and focusing on EDC removal from recycled water. Preliminary EDC removal information for ferric chloride coagulation, powdered activated carbon (PAC), MIEX combined with MF or UF, NF, and RO are presented.

30. Scherzinger, Remleh, Stefani Okaski, and David Frommell. "A Promising Prescription: Removal of PPCPs and EDCs in Wastewater through Advanced Separation Processes." 2006 AWWA Conference & Exposition, San Antonio, TX.

Presents summary findings from Sonoma County Water Agency's pilot study of the effectiveness of MF and RO in EDC removal following tertiary wastewater treatment. Effluent concentrations of a variety of EDCs are presented.

31. Scruggs, Caroline. "Effects of Wastewater Treatment on Microconstituents - Technical Practice Update." Water Environment Federation, May 2007.

Presents a "state of the industry" update on the issue of microconstituents in wastewater effluent and recycled water, including key issues, general efficacy of treatment technologies for microconstituent removal, regulatory approaches, and needed research.

32. Sinha, Shahnawaz, Zaid Chowdhury, Stuart Krasner, Paul Westerhoff, Baiyang Chen and and Bruse Rittman. "Improving Societal Benefit While Minimizing Wastewater-Derived DBPs to Potable Water: Approach to Cost-Benefit Analysis." 2006 AWWA Conference & Exposition, San Antonio, TX.

Presents median TOC concentrations for broad wastewater treatment categories (no nitrification, partial or poor nitrification, good nitrification, MBR, PAC/GAC, SAT, RO) based on a review of 20 US WWTPs.

33. Snyder, Shane A, Eric Wert, ongxia (Dawn) Lei, Paul Westerhoff, and Yeomin Yoon. "Removal of EDCs and Pharmaceuticals in Drinking and Reuse Treatment Processes." AWWARF 2007.

Presents the removal of EDCs and PPCPs by various conventional and advanced water treatment processes including:

- Physico-chemical processes: metal salt coagulation, chemical softening, activated carbon adsorption, granular media filtration, membrane filtration, and ion exchange
- Oxidation processes: chlorination, chloramination, ozonation (with and without hydrogen peroxide), UV irradiation (with and without hydrogen peroxide)
- Biological processes: biological filtration, riverbank filtration, SAT, aquifer storage and recovery (AST), and MBR

34. Snyder, Shane A., Paul Westerhoff, Yeomin Yoon, and David L. Sedlak. "Pharmaceuticals, Personal Care Products, and Endocrine Disruptors in Water: Implications for the Water Industry." Environmental Engineering Science Volume 20, Number 5 (2003).

Provides an overview of EDC and PPCP occurrence and a qualitative summary of removal efficacy of selected EDCs, PPCPs, and pharmaceutically active compounds (PhACs) by activated carbon, biologically active carbon (BAC), UV irradiation, chlorine / chlorine dioxide oxidation, coagulation / flocculation, softening / metal oxides, NF, RO, and degradation (biodegradation, photodegradation, and activated sludge degradation).

35. Snyder, Shane A., Samer Adham, Adam M. Redding, Fred S. Cannonc, James DeCarolish, Joan Oppenheimerb, Eric C. Werta, and Yeomin Yoon. "Role of Membranes and Activated Carbon in the Removal of Endocrine Disruptors and Pharmaceuticals." Desalination 202 (2006) 156–181.

Presents an evaluation of EDC and PPCP removal by membrane processes and applications at pilot- and/or full-scale, including: microfiltration, ultrafiltration, nanofiltration, reverse osmosis, electrodialysis reversal, membrane bioreactors, and combinations of membranes in series. Influent and effluent EDC and PPCP concentrations are presented.

36. Snyder, Shane and Eric Wert. "Treatment of Emerging Contaminants Using Membranes and Oxidation." 2006 AWWA Conference & Exposition, San Antonio, TX.



- Presentation summarizing results from “Evaluation of Conventional and Advanced Treatment Processes to Remove EDCs and PHACs” (AWWARF). Presentation focuses on RO, UF/RO, and MBR/RO pilot results, and includes removal data.
37. Song, Rengao, Ph.D. “Removal of Endocrine-Disrupting Compounds and Pharmaceuticals in Water Treatment.” Louisville Water Company.
- Summarizes EDC and PhAC removal efficiencies for activated carbon, BAC, ozone and advanced oxidation processes, UV irradiation, chlorine/chlorine dioxide oxidation, softening, NF, and RO.
38. Speitel, Gerald E., Mario M. Wanielista, James Symons, and Julie Davis. “Advanced Oxidation and Biodegradation Processes for the Destruction of TOC and DBP Precursors.” AWWARF 1999.
- Compares TOC removal from ozone/peroxide/biodegradation to UV/peroxide/biodegradation in drinking water.
39. United States EPA Office of Water. “Alternative Disinfectants and Oxidants Guidance Manual.” April 1999.
- Discusses TOC removal with alternative (to chlorine) disinfectants and oxidants.
40. United States EPA Office of Water. “Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual.” May 1999.
- Provides guidance for TOC removal in drinking water systems using metal salt coagulation, chemical softening, activated carbon adsorption, granular media filtration, and membrane filtration.
41. Westerhoff, Paul, Ph.D., P.E. “Removal of Endocrine Disruptors, Pharmaceuticals, and Personal Care Products During Water Treatment.” Southwest Hydrology, November/December 2003.
- Discussed EDC and PPCP removal using coagulation, lime softening, PAC, biofiltration, chlorination, ozonation, and membrane treatment.
42. Ying, Guang-Guo, Rai Kookana, and TD Waite. “Endocrine Disrupting Chemicals (EDCs) and Pharmaceuticals and Personal Care Products (PPCPs) in Reclaimed Water in Australia.” Australian Water Conservation and Reuse Research Program, January 2004.
- Provides a review of EDCs and PPCPs in recycled water in Australia as part of the Australian Water Conservation and Reuse Research Program (AWCRRP). The report summarizes existing Australian and international research on EDCs

and PPCPs, summarizes data on occurrence and environmental fate related to water reuse applications; provides an overview of potential effects and impacts of EDCs and PPCPs on ecosystem and human health; and identifies knowledge gaps and research needs.