Nanofiltration for Removal of Drinking Water Disinfection By-Product Precursors

The U.S. EPA Environmental Technology Verification (ETV) Program's Drinking Water Systems (DWS) Center, operated by NSF International under a cooperative agreement with EPA, verified the performance of the PCI Membrane Systems, Inc., Fyne Process Model ROP 1434 with AFC-30 nanofiltration membranes.[1] This nanofiltration system is designed to remove microbial contaminants in drinking water and reduce organic content that can act as a precursor in the formation of disinfection by-products (DBPs). Research has shown an association between DBPs, which include total trihalomethane (TTHM) and the sum of five haloacetic acids(HAA5), and cancer. Studies also show a possible association between DBPs and other, non-cancer human health impacts such as increased risk of adverse reproductive and developmental health effects.

Technology Description and Verification Testing

The ETV Program conducted verification testing for 57 consecutive days at the Barrow Utilities & Electric Coop., Inc., in Barrow, Alaska. Barrow is an Inupiat Eskimo village that draws raw water year-round from Isatkoak Reservoir, a surface water source that has moderate alkalinity, moderate turbidity, and an elevated organic content. Water quality data were collected on all source water, permeate, and concentrate streams produced by the PCI process and analyzed using Standard Methods for the Examination of Water and Wastewater, 20th Edition (1998), or EPA-approved methods. The tested system was equipped with a membrane module containing 72 tubular polyamide nanofiltration membranes connected in series. The system's small footprint, modular construction, and

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The PCI nanofiltration technology

DBPs and Their Regulatory Background at a Glance

DBPs are formed when disinfectants used for water treatment react with inorganic matter, such as bromide, and/or natural occurring organic matter (i.e., decaying vegetation) present in the source water. Different disinfectants produce different types or amounts of by-products. DBPs for which regulations are established have been identified in drinking water, including trihalomethanes, haloacetic acids, bromate, and chlorite.

To help address the potential health effects of DBPs, EPA has developed rules to control DBP formation. These rules, the Stage 1 and Stage 2 DBP rules, are part of a set of regulations that address risks from microbial pathogens and disinfectants/DBPs. Small drinking water systems, which EPA defines as those that serve fewer than 10,000 people each, were required to comply with the Stage 1 Disinfectants and Disinfection By-Products Rule (DBPR) by January 1, 2004. Under the Stage 1 DBPR, EPA has set standards for TTHM and HAA5 in drinking water of 80 and 60 micrograms per liter (µg/L), respectively. EPA also has enacted the Stage 2 DBPR to further reduce DBPs in drinking water systems with the highest risk levels. Drinking water systems serving fewer than 10,000 people are required to comply with Stage 2 DBPR TTHM and HAA5 monitoring by October 1, 2013, if no *Cryptosporidium* monitoring is required, or October 1, 2014, if *Cryptosporidium* monitoring is required. As a result of the Stage 1 and 2 DBPRs, certain drinking water systems may use treatment technologies similar to the ETV-verified PCI system to control formation of DBPs by removing the organic precursors. EPA includes nanofiltration among the best available technologies (BATs) for compliance with the Stage 1 and Stage 2 DBPRs.

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[1]The ETV Program operates largely as a public-private partnership through competitive cooperative agreements with non-profit research institutes. The program provides objective quality-assured data on the performance of commercial-ready technologies. Verification does not imply product approval or effectiveness. ETV does not endorse the purchase or sale of any products and services mentioned in this document.

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performance characteristics make it suited to applications from the smallest drinking water treatment systems to those that produce up to 50,000 gallons per day. The test skid produced an average of 0.87 gallons per minute of permeate when operated so that 80% of the raw water supplied to the test skid was recovered as permeate. The average transmembrane pressure and specific flux during the verification study were 88 psig[1] and 0.14 gfd/psi,[2] respectively. Some of the performance results are listed in **Table 1**.

Table 1. Average Performance of Selected Parameters of the Verified PCI Membrane Systems, Inc., Fyne Process Model ROP 1434

Parameter, units	Initial Value[1]	Final Value[2]	Reductions, %
Total organic carbon, (mg/L)	15	0.7	95%
UV_{254} absorbance	0.52	0.012	97%
Average TTHM formation potential in the source water, (µg/L)	544	31	94%
Average HAA5 formation potential in the source water, (µg/L)	405	6.7	98%
Iron, manganese, calcium, and sulfate from solution	varies	varies	47-99%

[1] Average Feed Water values at 95% confidence interval
[2] Average Permeate Water values at 95% confidence interval
mg/L, milligram per Liter µg/L, microgram per Liter

The ETV Program also verified the chemical cleaning performance of the PCI system. A single high-pH chemical cleaning cycle at the end of the two-month continuous verification test recovered at least 100% of the transmembrane pressure and specific flux measured at the start of the study. Performance was approximately the same before at the first day and after cleaning. The ETV tests also examined operation and maintenance needs, including labor and power requirements. The verification report can be found at http://www.epa.gov/etv/verifications/vcenter2-7.html.

[1]pounds per square inch gauge [2]gallons per square foot per day per pounds per square inch

Selected Outcomes of the Verified PCI Membrane Systems Nanofiltration Technology

ETV estimates, based on data from the Stage 1 and Stage 2 DBPRs, that approximately 4,800 drinking water systems will need to install new or modify existing treatment systems to comply with these rules.

Assuming 25% of the market install this device, the ETV Program estimates the following.
- The ETV-verified PCI nanofiltration technology would assist 1,200 small drinking water systems comply with EPA's DBP standards.
- For these systems, the technology could prevent up to 20 cases of bladder cancer per year.[1] The technology also could prevent other negative human health effects, including developmental and reproductive effects.
- The technology could result in economic benefits of up to $110 million per year due to the prevention of the above cases of bladder cancer.

Verification has also increased awareness of the ETV-verified nanofiltration technology and its benefits among state regulatory agencies and potential users. The following benefits have been or can be realized from the availability and use of the ETV data:
- Twenty-five states reportedly use ETV verification data to reduce the frequency and/or length of site-specific pilot tests for drinking water treatment and the vendor has reported this result in several installations of this technology. Drinking water regulations and guidance in several states identify the ETV Program as a source of performance verification data and testing protocols.
- Assuming 25% market penetration, 1,200 systems would use ETV data to reduce pilot testing requirements, saving up to $18 million in pilot testing costs.
- The reduction in pilot testing length also could lead to systems achieving the above health benefits sooner than would otherwise be possible.
- ETV verification has led to sales of the technology, resulting in reductions in exposure to DBPs with potential human health and associated economic benefits.

[1]In 71 FR 388, EPA acknowledges that causality has not yet been established between chlorinated water and bladder cancer and that the actual number of cases attributable to DBPs could be zero. Therefore, the actual number of cases avoided could be as low as zero.

References

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EPA/600/S-07/019
June 2007