Membrane Filtration Improves Water Quality at Point Beach Nuclear Power Plant

GLEN P. SUNDSTROM, USFilter Memcor Products, Rockford, IL, and DEAN M. WEYENBERG, Nuclear Management Company, Two Rivers, WI

PAPER NUMBER: IWC-05-15

KEYWORDS: Membranes, microfiltration, ultrafiltration, reverse osmosis, filtration, silt density index

ABSTRACT

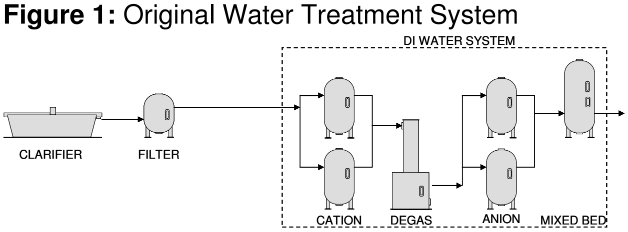
This paper discusses the technical, economic and operational issues addressed in improving RO feedwater to acceptable standards for the Point Beach Nuclear Plant. The final design, incorporating membrane filtration, resulted in a more economical and reliable system to operate and allowed full utilization of the capacity of the RO system.

BACKGROUND

We Energies' Point Beach Nuclear power plant, in operation since 1970, is a 1,036-megawatt, two reactor base-load facility located on Lake Michigan in Two Rivers, Wis. Nuclear Management Company, based in Hudson, Wis., assumed operation of the plant for We Energies in 2000, and also operates five other nuclear power plants in the upper Midwest.

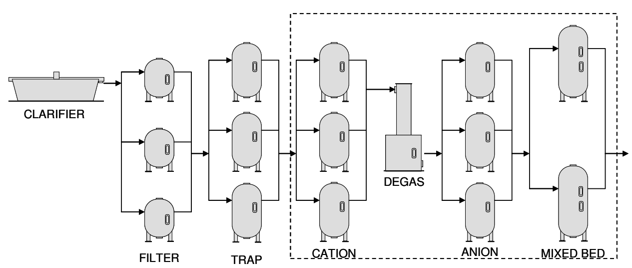
In 1970, We Energies was using the most widely accepted technology for demineralized make-up water. The original water treatment design consisted of intake screens; lime-softening solids contact clarifier, one multimedia filter, two cation exchangers, one vacuum deaerator, two anion exchangers, and a polishing mixed-bed demineralizer, as shown in Figure 1.

Figure 1: Original Water Treatment System



Poor make-up water quality, coupled with inadequate steam-system chemistry control, caused internal corrosion of the Unit 1 steam generators. The generators required replacement in 1983 after only 13 years of service, at a cost of nearly $90 million. In 1985, a 75,000-gallon lime softening solids contact clarifier was installed to replace the original 15,000-gallon clarifier, three multimedia gravity filters were installed to replace the original single filter, and three 150 cubic foot anion resin organic traps were added, as shown in Figure 2, in an effort to improve make-up water quality.

Figure 2: Expanded Water Treatment System



This system configuration produced better quality water; however, dissolved organic species continued to pass through into the steam generators, where heat broke these compounds down, releasing corrosive sodium, chloride and sulfate. By 1996, Unit 2 steam generators suffered internal corrosion and required replacement after 24 years of service, at a cost of nearly $130 million.

More changes were made to the steam system water chemistry to maintain better pH control throughout the system. In 1999, additional water treatment system improvements were made with the addition of three 100-gpm reverse osmosis (RO) units. The organic traps were converted to cation resin softeners and the RO units were installed at the effluent of the softeners, as shown in Figure 3. The purpose of these changes was to reduce the level of organic compounds reaching the steam generators. The water quality requirements for the steam generators were also increased, as shown in Table 1.

Figure 3: Modified Water Treatment System

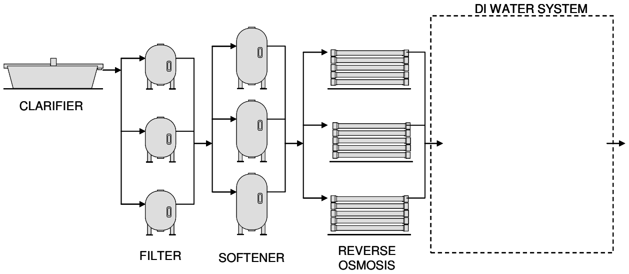


Table 1: Water Quality Parameter Changes

Parameter	Original Specification	New Specification
Resistivity (M-Ohm-cm)	>14	> 14
Silica (ppb)	<10	< 10
Sodium (ppb)	<5	< 1
Chloride (ppb)	<20	< 1
Sulfate (ppb)	Not Measured	< 2
TOC (ppb)	<200	< 5

After the RO units went on line, the water treatment plant experienced several new operational difficulties. The original lime softening approach created high pH conditions, which resulted in high sodium leakage from the RO system. Aluminum hydroxychloride coagulant addition replaced the lime, which eliminated the elevated pH problem. However, this was not the only difficulty that arose during operation of the plant.

Lake Michigan water, known for its widely fluctuating temperatures (35 to 70 deg F) and wide variations in turbidity (0.5 to 300 NTU), can be difficult to treat. Lake Michigan water quality is shown in Appendix A.

In order to maintain the performance of the RO systems, the clarifier and filters had to operate at optimum conditions. Perfecting the chemical program required constant adjustment related to fluctuating temperatures and turbidities as well as frequent variations in production flow rates. Figure 4 shows the variation in Lake Michigan turbidity, and Figure 5 illustrates the corresponding filter effluent turbidity.

Figure 4: Lake Michigan Turbidity

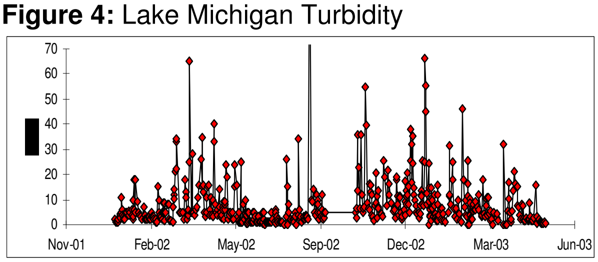
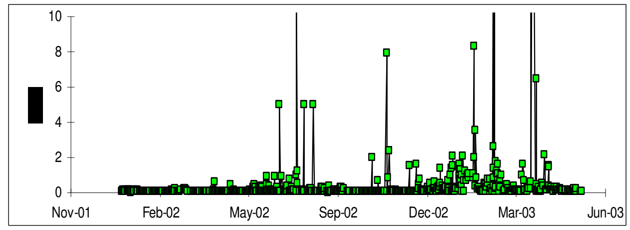


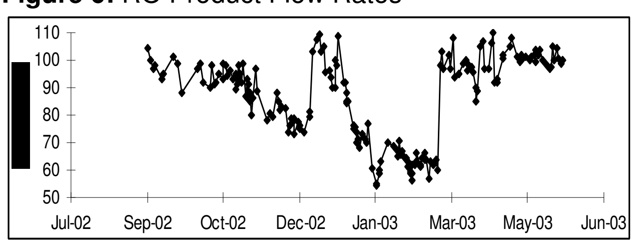
Figure 5: Filter Effluent Turbidity



Due to variations in water temperature, particle composition, and system flow rates, the filter effluent quality was not what would be expected, underscoring the difficulty in achieving acceptable system performance. Even when the clarifier and filters were operating at their peak performance, they were not able to remove all of the fine silt and biological debris, and this negatively affected the operation of the RO system. At best, the filters produced RO feedwater with a Silt Density Index (SDI) of 3, but more frequently, the SDI ranged from 4 to 6.

The RO systems are spiral-wound, five-stage units that operate at 75% recovery employing low pressure Dow FILMTEC LE-440i membranes. Due to the less-than-optimum feedwater quality, the RO systems required chemical cleaning approximately once every 90 days or less. During this 90-day period, the RO permeate flow rate would drop by as much as 40%, and the volume of high quality water required was not always available. During periods of peak demand -- during a reactor unit restart, for example -- the RO systems were occasionally by-passed to provide the quantity of water required. Due to the combined RO water production limitation of less than 300 gpm, this increased the amount of time required to blow down contaminants from the steam generators, which in turn caused expensive delays in returning the reactor to 100% power. Fig. 6 represents the RO system performance decline over time. In addition, the 5 micron pre-filters ahead of the RO system required frequent replacement, approximately every 5 to10 days, increasing consumable expenses, downtime and operating labor costs.

Figure 6: RO Product Flow Rates



In addition to the operation problems with the water system described above, the design created a significant amount of wastewater and sludge. The wastewater-sludge mix was pumped to a settling lagoon where the supernatant fluid was discharged to Lake Michigan. However, sludge accumulated in these sumps, and required trucking for off-site for disposal. This created additional and unpredictable expenses, including job planning with lock-out/tag-out procedures involving several people each time. The challenge increased even more when the settling lagoon was permanently retired in 2004. A new water treatment scheme was needed that would provide high quality water with minimal volume of waste.

OPPORTUNITY KNOCKS

When the plant's license came up for renewal, We Energies decided it would be best to upgrade the water treatment plant with a design proven to be economical for the next twenty years of operation. The objectives for the upgrade were:

- Eliminating on-site waste storage and handling
- Improving reliability of the water treatment system
- Reducing operating costs of the water treatment system
- Reducing or eliminating wastewater discharge
- Reducing or eliminating sludge generation and disposal

Since commercial operation of the plant began, there had been advances in clarifier design, polymer chemistry and dose control. However, the numerous drinking water membrane filtration installations on Lake Michigan indicated that this technology was a potential alternative. It was clear that membrane filtration provided superior effluent quality for drinking water than did conventional technology. In addition, membrane filtration as pre-treatment to RO is a well-established technology. Some of the most widely publicized and recognized examples of membrane filtration technology are in California at West Basin Water Recycling Facility and Orange County's Water Factory 21. There are also numerous examples in the power and steam generation industry, including Brooklyn Naval Shipyard, Alabama Power, Cinergy and Eraring Energy.

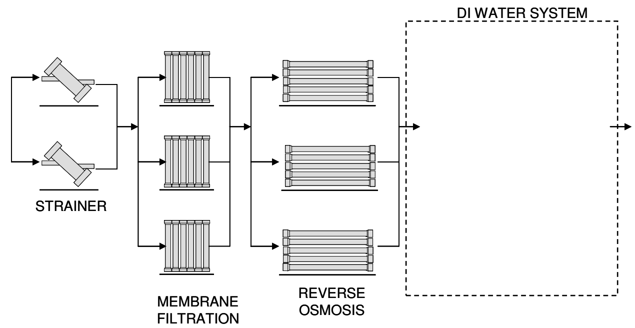
SOLUTION

After an exhaustive investigation and evaluation of treatment alternatives, Point Beach installed a Memcor® microfiltration system to replace the chemical feed, clarifiers and multimedia filters which is shown in Figure 7. The microfiltration system employs PVDF membranes with a 0.1 micron rating. By eliminating the chemical feeds, the clarifier, and the multimedia filters, the unadulterated backwash wastewater from the membrane filtration system is routinely discharged directly back to Lake Michigan. This eliminated the on-site accumulation and processing of solid waste. The wastewater characteristics shown in Table 2 indicate significant reduction in wastewater volume and virtually eliminating the sludge.

Table 2: Wastewater Characteristics

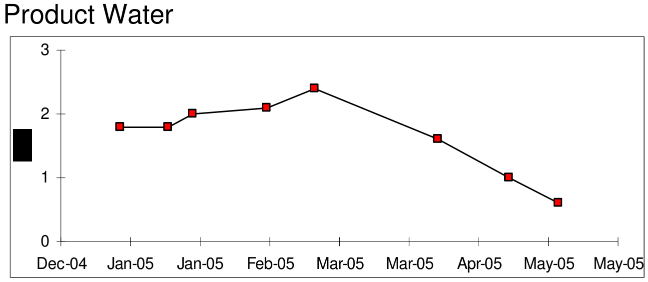
Parameter	Before	After
Volume (gallons/day)	275,000	<100,000
Sludge volume (gallons/month)	3,000	no measurable sludge

Figure 7: New Water Treatment System Incorporating Membrane Filtration



As seen in Figure 8 below, the SDI of the product water from the membrane filtration system is consistently below 2.0, regardless of the influent turbidity from January 2005 through May 2005. These SDI values are ideal for optimum RO system performance. The reliable effluent quality allowed the RO system to operate at full design capacity, without unplanned downtime. High quality water was available on demand. Another indication of improved RO system performance was the elimination of RO feedwater booster pumps during the winter months. Before, these pumps were required to ensure 100-gpm product output from each RO unit.

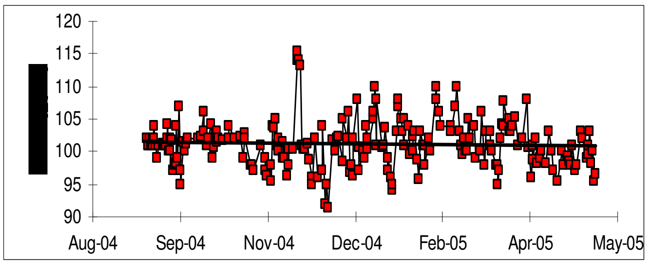
Figure 8: SDI of Membrane Filtration System Product Water



Operation of the membrane filtration system has been stable over the last nine months. As a preventative maintenance procedure, the MF system undergoes a chlorine wash once per month, and an acid wash once per quarter.

Removal of silt and biological debris by the membrane filtration system greatly improved performance of the RO system. Figure 9 shows the performance of the RO system from September 2004 through May 2005. The variations in RO flow rate are due to varying plant water needs alone. Note: at the time of this paper, none of the three RO units has required a chemical cleaning after nine months of continuous operation. This is quite an improvement from the previous RO operation, which required cleaning at least every 90 days.

Figure 9: RO System Production



This new, simplified system provided all of the technical and ecological solutions desired to support future plant operation.

- Improved reliability of the entire water plant
- Reduced waste generation
- Reduced RO membrane fouling

BOTTOM LINE

The upgrade provided many benefits to the plant. Those easily quantified benefits, shown in Table 3, reveal with a total project cost of approximately $3.5 million, and an annual operating cost savings of $614,000, the new system will pay for itself in six years or less. Other benefits that are not easily quantifiable, such as the reduced time to restart from an outage described above, are shown in Table 4.

Table 3: Quantitative Analysis

Criteria	Before	After	Savings
Cleaning Chemicals	$122,000	$24,000	$98,000
Consumables	$9,000	$2,000	$7,000
Labor (est.)	$525,000	$65,000	$460,000
Wastes	$54,000	$5,000	$49,000
Total	$710,000	$96,000	$614,000
Total project cost		$3,500,000	
Operating cost savings		$614,000 per year	
Simple payback		6 years	

Table 4: Qualitative Analysis

Criteria	Before	After
Reliability	Unreliable Unpredictable	Reliable Predictable
Operation	Difficult Labor intensive	Simple Routine maintenance
Environmental	High impact	Low impact

CONCLUSION

Membrane filtration has greatly improved the water quality at Point Beach Nuclear Power Plant. The plant has significantly reduced its operating costs, increased the reliability of the water treatment plant, and reduced the waste associated with the water treatment system. Membrane filtration was an economical and ecological choice for this power plant, and its success has led others to incorporate similar systems. Moreover, recent advances in membrane filtration systems will further reduce their operating costs.[1]

REFERENCES

1. Sundstrom, Glen, P., and Swerdfeger, Russ, J., IWC-05-75 paper

APPENDIX A

Lake Michigan Water Quality

Parameter	Concentration
pH	8.3 s.u.
Sodium	5 - 6 ppm
Chloride	11 - 12 ppm
Sulfate	20 - 22 ppm
Nitrate	0.2 0- 0.3 ppm
Iron	<20 ppb
Calcium	35 - 37 ppm
Magnesium	10 - 12 ppm
Potassium	1.1 - 1.5 ppm
Copper	3 - 5 ppb
Alkalinity (as $CaCO_3$)	110 - 120
Total Hardness	120 - 130 ppm
Total Conductivity	250 - 350 µS
Total Organic Carbon	0.5 - 175 ppm
Total Suspended Solids	0.2 - 500 ppm
Particle Size Distribution	80% <2 µm
Total Dissolved Solids	150 - 170 ppm