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Membrane Softening:
An Emerging Technology Helping Florida Communities Meet the Increased Regulations for Quality Potable Water

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Florida's population is growing faster than any other state's. This growth has led to rapid development of residential communities and businesses, and increased demand for potable water. However, much of the state's drinking water is drawn from shallow local wells tapping brackish aquifers high in organics, color, and bacteria. Membrane softening, based on the use of nanofiltration membranes such as FILMTEC® NF70 membrane, has emerged as an effective, practical, and economical treatment option for municipal and private utilities faced with the challenge of meeting increasing demand for high quality potable water.

Lime softening, coupled with chlorination, has traditionally been used in many areas of Florida to treat local water so that it is safe for human consumption and free of objectionable tastes, odors, and color. In lime softening processes, hydrated lime and other chemicals are added to the water supply in order to induce precipitation of hardness in the form of calcium carbonate and magnesium hydroxide. Chlorine or other disinfectant chemicals are added after softening to remove color and disinfect the water before it enters the distribution system.

Although still widely used, lime softening has become a less attractive water treatment alternative for a number of reasons. First, continuing residential, commercial, and industrial development and the significant amount of land required to operate a lime softening facility have made suitable plant sites increasingly difficult to find in many communities. Second, sludge produced by the lime softening process must be landfilled, an expensive and dirty operation. Third, lime softening operations do not offer the flexibility water authorities require to add incremental plant capacity as system demands increase. Fourth, and most important of all, there is a growing concern about the potential formation of suspected cancer-causing compounds called trihalomethanes (THMs) when chlorine comes into contact with certain organics remaining in the water after lime softening.

Sodium chloride (NaCl) zeolite softening is also used in some areas to treat municipal water. However, the high level of salt in the brine solution discharged during regeneration of a NaCl zeolite softener can have an unacceptable environmental impact and the discharge may be subject to strict regulatory controls.

For these reasons, an increasing number of Florida water utilities are investigating and adopting membrane softening technology to meet their potable water requirements.

What is Membrane Softening?

Membrane softening is a term applied to a water treatment process that uses nanofiltration (NF) membrane technology to reduce hardness and remove organics, color, bacteria, and other impurities from the raw water supply. Nanofiltration is often referred to as modified reverse osmosis (RO) because it is based on very similar operating principles. Like RO, nanofiltration is a pressure-driven separation process that employs a semipermeable membrane and the principles of cross-flow filtration to split a feedwater stream into two parts—a purified "permeate" water stream and a waste "concentrate" stream containing a high percentage of the impurities found in the raw water.

Although RO separation is necessary for seawater desalination and for treatment of brackish water containing very high levels of dissolved solids, many water supplies do not require the almost total salt removal provided by RO. Membrane softening using nanofiltration membranes is an option when very high level salt rejection is not necessary or even desirable. NF membranes partially demineralize water, removing between 10% to 90% of dissolved salts compared to up to 99.5% for RO. But like RO, NF membranes remove a very high percentage of organics—which cause objectionable color, tastes, and odors—as well as the vast majority of bacteria, viruses, and other contaminants such as Radium 226, sulfates, colloidal materials, and heavy metals. For this reason, membrane softening using nanofiltration membranes is often described as "partial demineraliztion but total water treatment." The level of salt rejection depends on which product, from the variety of available NF membranes, is used.

Water drawn from many shallow aquifers in Florida do not require high level salt rejection. In fact, in many cases only partial salt rejection is desirable. The low-level calcium hardness remaining in NF permeate imparts a "sweet" taste to the water. And it provides a slight scaling tendency necessary to prevent corrosion of water lines and subsequent contamination of the water supply due to leaching of copper, lead, or other metals.

Disposal of the concentrate waste stream produced by NF plants is often less involved than disposal of concentrate produced by RO plants. RO concentrate typically contains very high levels of Total Dissolved Solids (TDS). This is due to the high TDS levels of the raw water supplies typically treated using RO separation and the high salt rejection capabilities of RO membranes.

In contrast, nanofiltration is normally used to treat water containing less than 2000 mg/l of TDS and the less complete salt rejection capabilities of NF membranes produce concentrate containing less than 4000 mg/l of TDS. Salt levels in NF membrane concentrate are also significantly lower than those found in the brine solution discharged from a NaCl zeolite softener.

Lower TDS levels mean concentrate from NF membranes can sometimes be used directly or diluted with water from domestic waste water treatment plants and used to irrigate golf courses and parks where the turf benefits from the moisture as well as from the high organic content of the concentrate. Other concentrate disposal methods available to operators of membrane softening plants can include surface water discharge, evaporation, and deep well injection.

An important factor in many communities' decisions to use membrane softening is increasing concern about trihalomethane formation potential (THM) and government regulations designed to limit public exposure to this suspected carcinogen. Trihalomethanes are chlorinated hydrocarbons that can be formed when chlorine and other chemicals are used as a post-treatment to "bleach out" color and to disinfect water produced by lime softening and other conventional water treatment operations.

NF membranes remove most THM precursors from the raw water supply. And because NF membranes effectively remove color bodies and bacteria, chlorine addition rates for membrane-softened waters are greatly reduced. That means THM formation in the treated water supply is almost entirely eliminated.

When the high degree of salt rejection available with RO separation is not required, membrane softening with nanofiltration membranes is a highly practical and economical option. Nanofiltration operates at significantly lower pressure than reverse osmosis, which means the energy expense associated with the use of nanofiltration is far lower than with RO. While RO systems typically operate between 200 psig and 300 psig, NF processes operate in the range of 75 psig to 150 psig. As mentioned earlier, disposal of concentrate from NF plants can be easier and less costly than that produced by RO processes because salt concentrations in the wastewater are far lower.

Nanofiltration is also a highly cost-effective option when compared to lime softening. The initial cost to install an equal amount of NF or lime softening capacity is about the same, but membrane plant expansions are easier and less costly than expansions of lime softening facilities. What's more, because lime softening capacity must be installed in large increments, it is often necessary to install and pay for excess capacity in advance to accommodate projected growth in demand. Membrane technology, on the other hand, can be installed in much smaller increments and capacity can be added and paid for as it is needed.

Operating costs for membrane softening plants are often lower than for lime softening facilities, too. With NF, the need for costly pH adjustment is reduced, chlorine disinfectant requirements are lower, and the expense of sludge disposal is eliminated.

Also contributing favorably to the cost advantages of membrane softening are the reduced land requirements involved. Membrane plants require about one-third of the space of lime softening plants. As open space becomes developed and the value of land increases, this can mean major site acquisition savings. In developed areas, large tracts of land suitable for construction of new lime softening plants—or for expansions of existing facilities—are often simply not available. And even where suitable sites are available, the appearance, dust, odors, and other disturbance related to sludge disposal and overall plant operations can make large-scale lime softening plants unacceptable to neighboring property owners and to the overall community.

Membrane softening was first explored as an option for treating water from Florida aquifers in the mid-1970s. The first systems were based on cellulosic membranes. However, the technology began to achieve widespread acceptance in the mid-1980s with the introduction of thin-film composite nanofiltration membranes capable of operating at significantly lower pressure and offering high resistance to biodegradation. One of the earliest installations of a nanofiltration system was for supplying water to a southeastern Florida elementary school. When the School Board of Palm Beach County developed plans for a new elementary school to serve neighborhoods in the Loxahatchee Groves area, a serious water supply problem had to be addressed. The proposed building site was more than five miles from the nearest municipal water lines and extending those lines was considered prohibitively expensive. Trucking water to the school was also deemed impractical. Short of abandoning the project altogether, the only available option was to drill wells to tap the shallow local aquifer. Unfortunately, the quality of the well water in the area is very poor. It contains high levels of bacteria, plus more than 500 mg/l of total dissolved solids. What's more, naturally occurring organics and synthetic organic compounds from agricultural activities also contributed to the contamination.

This organic contamination is responsible for color in the water as well as the presence of THM precursors that have the potential to form cancer-causing compounds when chlorine is added to disinfect the water. Other undesirable contaminants in the water are hydrogen sulfide (H2S) and iron.

After exploring treatment alternatives, Hutcheon Engineers, a Division of Kimley Horn Associates of West Palm Beach, Florida, proposed installation of a nanofiltration membrane softening facility based on the FILMTEC NANOFILM™ NF70 thin-film composite membrane. The new system—designed and built by ITEK International of Hollywood, Florida—was installed and in full service when Loxahatchee Groves Community Elementary School opened in August of 1987.

Located in a small building adjacent to the school itself, the system is configured in a 4-3-2 array with four FILMTEC NF70 elements in each pressure vessel. Operating at 125 psig, at a flux of 17 gallons per square foot per day (gfd), and 75% recovery, the system has a production capacity of 42,000 gallons of high quality water per day. The system removes more than 97% of total organic halogens from the well water and more than 90% of total organic carbon (TOC). Seven-day trihalomethane formation potential has been reduced to 56 micrograms per liter (µg/l) from a concentration of 630 µg/l in the raw well water. Water hardness is reduced 92%. Today, the original membranes continue to supply 100% of the school's water requirements. The success of this pioneer system has helped with the construction of two more elementary schools in remote areas of Palm Beach County, both of which utilize FILMTEC NF70 elements.

The early success achieved by membrane softening technology in Palm Beach County's schools was a significant starting point. Today, the increasing number of membrane systems across Florida—and growth in the size of those plants—are strong evidence that membrane softening is a cost-effective answer to pressing drinking water needs.

On the following pages are profiles of two major membrane softening plants that have been installed since 1991 by private and municipal utilities to serve the water quality needs of residents in two of Florida's fastest growing areas. While communities in the state of Florida are at the forefront in the use of membrane softening technology, nanofiltration's potential to secure the quality of community drinking water supplies extends far beyond the borders of a single state. Increasing water demand—coupled with the stiffening challenge of producing safe drinking water from organic-laden surface and groundwater sources—suggest that communities outside of Florida will also turn to membrane softening and nanofiltration membranes to ensure future supplies of high-quality drinking water.

Corkscrew Plant

When demand for potable water outgrew the capacity of an existing lime softening plant, Gulf Utility Company of Estero, Florida, began planning construction of a second treatment facility. This private utility draws water from local wells and supplies the potable water needs of several communities in Lee County, south of Fort Meyers.

The quality of the water from the local aquifer is poor, both from a health and from an aesthetic standpoint. It contains high levels of naturally occurring organics, significant trihalomethane formation potential (THMFP), and high iron content that results in a high degree of color which can stain porcelain plumbing fixtures, laundry, and other materials contacted by the raw water. Although an effective answer to high water hardness, lime softening processes do not adequately remove organics and bacteria from the water supply. This means high levels of chlorine or other chemicals must be added to lime softened water at the post-treatment stage to remove objectionable color and to disinfect the water so it is safe for human consumption. But high disinfection addition rates increase the potential for formation of disinfection byproducts (DBP) including THM, a suspected cancer-causing agent formed by the combination of chlorine and some naturally occurring organics.

Gulf Utilities decided to explore membrane softening as an alternative to lime softening because of concern about THMFP and anticipated more stringent government regulations to protect human health from this suspected cancer threat. Other factors favoring the use of membrane softening included the expansion flexibility possible with a membrane facility to accommodate future growth in water demand, the significantly smaller plant site requirements, and the fact that lime sludge disposal would not be required.

Initial specifications for the plant were developed in late 1989. However, water quality projections based on generalized assumptions of membrane performance in the proposed system indicated that the water's high iron content might not be corrected by the use of nanofiltration alone. Project engineers proposed adding a feedwater pretreatment system to reduce the iron content ahead of the membranes, but projections showed this pretreatment approach was prohibitively expensive.

Gulf Utilities called upon Stone & Webster Engineering to develop an alternative design to see if a less expensive membrane plant was possible. To obtain specific membrane performance data, the engineering firm prepared a pilot unit and tested the performance of several commercially available NF membranes from December 1989 through May 1990. The engineers found that the FILMTEC NF70 membrane could reduce the iron content of the water from 4 ppm to 0.1 ppm—significantly more than the other elements in the test. What's more, pretreatment requirements with the FILMTEC NF70 elements included only normal use of an antiscalant to prevent membrane scaling and acid addition to reduce the feedwater pH.

As a result of these findings, Gulf Utilities authorized construction of the plant which was brought on line in the Spring of 1991. The plant consists of 114 FILMTEC NF70-8040 elements in one train. The 19 pressure vessels are arranged in a three-stage, 11-5-3 array with each vessel containing six elements. Five micron cartridge filters are positioned ahead of the train to remove silt and other particulate matter from the feedwater to protect the membrane elements against plugging. Permeate produced by the membranes is directed to a cascade-type aerator to remove the low levels of hydrogen sulfide (H_2S) gas present. Caustic soda (sodium hydroxide) is added to raise the pH of the water and chlorine is injected as a disinfectant to ensure that biological activity is controlled during storage and distribution. Water produced by the membrane softening facility and Gulf Utilities' lime softening plant is delivered to the utility's service area by a common distribution system.

The Corkscrew plant has operated at full capacity since coming on line, producing 500,000 gallons per day (gpd) in the first four years of operation, or an average of 35% of Gulf Utility's total two-plant production. Operating at a feed pressure of 120 psig, with recovery set at 80%, and flux of 15.6 gfd, the system reduces total organic carbon (TOC) in the water 90%, from 10.6 parts per million (ppm) to less than 1 ppm. Total dissolved solids (TDS) are reduced from 553 ppm to 43 ppm. Hardness is reduced from 313 ppm to 16 ppm (as $CaCO_3$). As an added margin of safety in meeting the plant's iron removal goals, the system was designed so that a portion of the permeate water is recirculated to dilute the feedwater to the membranes. This has helped the plant to consistently maintain iron levels between 0.1 ppm and 0.2 ppm in the finished water, below the target level of 0.3 ppm.

Gulf Utilities receives an added bonus from its membrane plant in the form of an organic-rich concentrate waste stream. This concentrate is fed to the utility's domestic wastewater treatment plant where it is mixed and treated with other wastewater and then used to irrigate and fertilize local golf courses. Unlike RO concentrate which has a very high salt content, the diluted NF concentrate is lower in salt yet is high in organic content, making the treated wastewater an excellent fertilizer for the golf course turf. By reusing the concentrate, the cost of injecting it into deep disposal wells is avoided. Also, the use of enriched wastewater for golf course irrigation means more of the purified water produced by Gulf Utilities' membrane and lime softening operations remains available for potable use.

The building housing the Corkscrew membrane softening plant was constructed larger than was needed initially to allow for two incremental future expansions of 500,000 gpd each. The first of these expansions was initiated in 1994, increasing plant production capacity to one million gallons per day (mgd) starting in January 1995.

City of Boynton Beach

The City of Boynton Beach is on the Atlantic Coast in fast-growing southeastern Florida. In the late 1980's, it became apparent to the municipal water authority that the growing demand for drinking water resulting from development in the western part of the city would overtake the capacity of the city's lime softening plant by mid-1990s.

To expand the supply of water to meet increased demand, a new well field and water treatment facility were planned for a site five miles west of the existing plant.

Because the new plant would be located in a fast growing residential area, there were practical limits on how large the plant site could be. To satisfy current and future property owners in the area, the plant would have to be designed to be compatible with surrounding neighborhoods. The plant could not have an "industrial" appearance and the potential for objectionable odors, noise, dust, and other operating disturbances had to be minimized.

The plant would have to treat nonpotable water drawn from wells tapping the local aquifer. The shallow aquifer contains approximately 290 mg/l of hardness (as $CaCO_3$) and is high in color (45 pcu). Seven-day THMFP is greater than 400 µg/l. TOC is 20 mg/l, while TDS content is 377 mg/l. As in many communities treating organic laden water with high levels of bacteria, water authorities in Boynton Beach were concerned about reducing disinfectant chemical addition rates in view of the suspected cancer threat posed by trihalomethane formation. The new plant would have to be designed with an eye on compliance with anticipated government regulations of disinfection byproducts in drinking water supplies.

Safety was another concern in Boynton Beach's desire to reduce chlorine use. In 1978, the city experienced a significant chlorine leak at its lime softening plant and every effort has been made since that time to minimize the likelihood of another discharge.

It was decided that building a second lime softening plant posed potential problems. First, lime softening might not produce water meeting stricter government standards for THMFP in drinking water. Second, water produced by a lime softening plant might not be acceptable to consumers due to potential problems with color, odor, and taste. Third, a lime softening facility would require a large site and would require sludge disposal on-site or truck transportation of the sludge to a remote location. And finally, the plant would have an industrial appearance and its operations would be dirty, noisy, expensive, and incompatible with the plant's residential location.

Membrane softening based on nanofiltration membrane separation technology was investigated as an alternative water treatment method because of its ability to reduce hardness to desired levels while also removing organics and bacteria. Removing organics and bacteria in this fashion can significantly reduce chlorine post treatment requirements for color removal and disinfection.

This means the potential for THM formation is greatly reduced and the ability to meet stricter drinking water standards for disinfection byproducts is enhanced. Reduced disinfectant requirements also lower the risk of chlorine leaks that can pose a safety hazard to plant personnel and residents of the surrounding community.

The city in conjunction with Post, Buckley, Schuh, and Jernigan began investigating the feasibility of membrane softening in 1987 and conducted a 3,000 hour pilot test at the proposed plant site using FilmTec Corporation's mobile pilot plant. The mobile pilot plant was equipped with FILMTEC NF70-4040 nanofiltration elements and hooked up to a well on the plant site. The membranes met the city's targets for TDS, organics, and color removal in this initial test and a second 1,000 hour test showed that the membranes also achieved the target for THMFP removal.

Design work by CH2M Hill for the new West Water Treatment Plant was begun upon completion of pilot testing, and L*A Water was awarded the contract to install the new nanofiltration membrane system. The system contract was contingent on completion of a successful 1,000 hour proof test simulating the proposed plant's actual operating performance.

This proof testing was conducted using the FilmTec mobile pilot plant equipped with FILMTEC NF70-4040 elements and hooked up to wells on the plant site. Water samples taken at 200 hours and 800 hours confirmed that the membranes produced water meeting the city's quality standards. Inspection after 1,000 hours showed that the membranes remained stable during the test period. With the final testing completed, construction was initiated and the plant was brought on line in June 1994.

The plant includes three membrane trains, each with a capacity of 1.33 mgd. A total of 648 FILMTEC NF70-345 membrane elements are installed in 108 pressure vessels. Each train includes 36 pressure vessels arranged in a two-stage, 26-10 array. Feedwater to the plant is prefiltered through five-micron cartridge filters to prevent buildup of silt and other particulate matter on the membranes. The filtered water is then pretreated with sulfuric acid to reduce pH. A scale inhibiting chemical is added to prevent scaling on membrane surfaces.

The concentrate produced by the membranes is discharged to a deep well located on the plant grounds. Membrane permeate is directed to degasifiers to reduce the hydrogen sulfide (H_2S) and carbon dioxide (CO_2) content of the water. Each degasifier is equipped with a caustic/chlorine scrubbing tower to minimize discharge of foul odors that might be noticeable to neighboring residents.

To reduce the acidity of the finished water, pH is raised to 8.2 through addition of caustic soda (sodium hydroxide). To further ensure that corrosion is not a problem in the distribution system or in household water lines, a minimum specification for permeate alkalinity is set at 70 ppm (as $CaCO_3$). The minimum requirements for calcium hardness passage through the membranes is 50 ppm (as $CaCO_3$). In the final post treatment step, chlorine and ammonia are added to the permeate to prevent bacterial growth. The plant requires 1/15th the amount of chlorine as a lime softening facility of the same capacity. To minimize a potential safety hazard, a scrubbing device has been installed to neutralize chlorine in the event of disinfectant chemical leakage at the plant. Finished water from the plant is pumped into a three million gallon storage tank to await distribution.

Great care was taken to design the exterior of the plant to be compatible with the surrounding residential neighborhoods. The main process building of the plant is designed to have a non-industrial appearance and extensive "xeriscape," low-maintenance (and low irrigation) landscaping providing a buffer between the plant and its neighbors.

The Boynton Beach membrane softening plant now produces 4 mgd of the total 12 mgd of potable water the City of Boynton Beach supplies to its customers. Operating at a feed pressure of 100 psig, with recovery set at 80%, and flux of 18.7 gfd, the system reduces TOC in the water to 2 mg/l. TDS content is reduced to 120 mg/l. The finished water has a hardness of 50 ppm as $CaCO_3$ and an alkalinity of approximately 75 ppm as $CaCO_3$. Both the hardness and alkalinity meet the minimum specifications set for the plant. The total THM content of water produced by the West Water Treatment Plant is below detectable limits based on samples drawn from the distribution system. Color has been reduced to less than 1 pcu.

Although the West Water Treatment Plant is currently producing at its full capacity of 4 mgd, city officials were thinking far beyond Boynton Beach's immediate water demand when they designed the plant. The main process building of the plant was constructed to allow for incremental expansions in capacity up to 8 mgd, while the plant site was planned to accommodate expansion to a total buildout of 16 mgd. In fact, the concentrate disposal capacity of the membrane facility is already based on total water production of 16 mgd. Current degasifier, finished water storage, and high service pumping capacities of the plant are all designed for production of 8 mgd with provisions for expansion to 16 mgd.

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