Membrane Concentrate Reuse By Controlled Blending

Steve Messner, Geoff Hart, John Netzel, and Jonathan A. Dietrich

Gulf Utility Company's Corkscrew Water Treatment Plant treats water from a surficial aquifer in Lee County with a nanofiltration or membrane softening process. The raw water supply to the plant has a TDS concentration of 500 mg/L, predominantly calcium bicarbonate. The raw water is typical of other surficial aquifer supplies in South Florida, except for the total iron concentration, which ranges from 4 to 6 mg/L.

Sulfuric acid dosing to a pH range of 5.2 to 5.6 is used to prevent alkaline scale formation in the membranes and to retard the oxidation of iron. The plant also has the capability of dosing a threshold scale inhibitor, but that has not been used since the first year of operation. Acidification destroys most of the alkalinity and changes the acidified feed water to a predominantly calcium sulfate solution.

The plant began operation in 1991 with a single treatment train having a capacity of 0.50 MGD. It was initially operated at a recovery of 75% and a low-feed pH to control permeate iron concentration. As the original FilmTec NF 70 membranes "tightened up" and two additional skids utilizing higher rejection FilmTec membranes were added, recovery was increased to 80 to 85%, and acid dosing was reduced.

The plant currently produces up to 1.80 MGD of product water and between 320,000 and 450,000 gpd of concentrate, depending on recovery. The concentrate has a TDS concentration of approximately 3,600 mg/L at a recovery of 85%, of which approximately 1,500 mg/L is the sulfate ion. At a recovery of 80%, these concentrations are 20% lower.

Since the plant went on-stream, its concentrate and the effluent from the utility's Three Oaks Wastewater Treatment Plant have been disposed of by spray irrigation on two nearby golf courses: the Vines Country Club and the Villages at Country Creek. The concentrate and the effluent were mixed in-line as both plants freely discharged into the common reuse transmission system that supplied the golf courses. Concentrate from the membrane trains was discharged into a wetwell via an air gap and then pumped directly into the reuse system. Monitoring of background groundwater quality at the golf courses indicated that it was not being influenced by reuse flow composition, and this mode of operation was permitted up to a concentrate flow of 250,000 gpd.

The overall ratio of flows historically delivered to the golf courses has approximated 70% effluent/30% concentrate. Because the water and wastewater service areas largely coincide, there is some linkage between these flows. The flow ratio will tend to approach 80% effluent/20% concentrate as system demand increases. However, the blend received at each golf course holding pond has been different, with the Vines course receiving primarily effluent and the Country Creek course receiving most of the concentrate.

In 1996 the plant was expanded to its present capacity of 1.80 MGD with a corresponding increase in concentrate flow up to 450,000 gpd. The capacity of the Three Oaks WWTP was also expanded to an effluent capacity of up to 750,000 gpd. In discussions with DEP it was determined that obtaining the necessary permits to construct and operate the Cork-screw WTP and the Three Oaks WWTP would require a system that would provide controlled blends and quantities at the two golf courses and the new Pelican Sound development. The system must meet DEP criteria of providing assurances of maintaining groundwater quality standards within the zones of discharge as stipulated in regulations relating to groundwater monitoring programs (Chapter 62-610 FAC - Reuse of Reclaimed Water and Land Application).

System Description

Three options were considered by Gulf Utility Company and Montgomery Watson to satisfy the permitting criteria. The first was the installation of dual transmission lines to each site to allow the concentrate and effluent to be pumped independently with blending occurring in the receiving ponds at each reuse site. The installation of additional lines would increase the cost considerably above that of the existing single 12-inch system.

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The second option was to discontinue concentrate reuse by constructing an injection well at the Corkscrew WTP. This would be the most costly of the options considered and would also be the first dedicated concentrate disposal well in Lee County.

The third option was controlled blending of concentrate with effluent in the receiving ponds at each reuse site by sequential pumping of each through a single transmission system. This option would require construction of concentrate storage capacity at the Corkscrew WTP and a relatively sophisticated control system. The Three Oaks WWTP already had effluent storage tank capacity. After some preliminary planning, it was decided to proceed with the construction of the third option. Gulf Utility Company subsequently received a grant from SFWMD to defray part of the construction costs of the modifications.

The biggest change at the Corkscrew WTP was the construction of a 1.0 mg prestressed concrete Crom concentrate storage tank. The tank was fitted with four Butterworth tank cleaning machines to eliminate the need for periodic manual cleaning. After considering several options, it was decided to pipe concentrate from the membrane trains directly to the top of the tank where an air gap is provided. That increases concentrate back pressure slightly, but it remains well within acceptable limits. From the tank, the concentrate flows by gravity into the existing wetwell via a level control valve. Two new 650 gpm concentrate pumps and a hydropneumatic surge vessel were designed with the flexibility to be used either with the reuse system or a future injection well.

Each of the three reuse sites is equipped with a monitoring and control station, including a flow meter, a flow control valve, a pressure transmitter, a conductivity analyzer, and a PLC-based smart Remote Terminal Unit (RTU). The conductivity analyzer is essential for distinguishing between effluent and concentrate since the transmission piping contains approximately 200,000 gallons of water. When pumping is switched from effluent to concentrate, for instance, it takes almost a day for concentrate to reach the Vines. Blending stations are configured to allow either semi-autonomous operation in a flow or pressure control mode, or to receive control commands from the SCADA master station.

A SCADA system links the two treatment plants, the three reuse sites, and the Gulf Utility Company operations center for a total of six different locations. The treatment plants are also equipped with RTUs, and the master station is located at the operations center.

Operating Experience

It became apparent when the system was started up that each part of the pumping cycle had to be relatively long to clear the transmission line. The reason is that the transmission line holdup is large relative to daily flows, which currently average about 700,000 gpd for the system. The system operates on a five-day cycle with three days for effluent pumping from the WWTP and two days for concentrate pumping from the WTP. During the off cycle at each plant, water accumulates in the storage tanks. As flows increase in the future, shorter cycles will be used.

The cycle is initiated at the WWTP when the operator enables the

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The City of Hollywood's Experience with Multi-Source Membrane Treatment Processes

Frederick Bloetscher and Roberto S. Ortiz

South Florida, like many areas of the world, is facing challenging water supply issues. While the region receives an average of 60 inches of rainfall each year, the rainfall is offset by a high evapotranspiration rate, which removes 70% of the total rainfall from the water budget. In addition, the subtropical climate causes pronounced wet and dry seasons, where over 70% of the area's precipitation occurs between June and October, which is the only time of year when rainfall actually exceeds the evapotranspiration rate.

Extensive canal systems constructed after the turn of the century to drain the coastal swamps, allow development, and eradicate mosquitoes now drain away 24% of the total rainfall to the ocean and keep the aquifer system 3 to 4 feet below its historical, predevelopment level (the top 4 feet of the aquifer system has been permanently drained away). The result is a limited amount of water remaining to recharge the Biscayne aquifer system. This small recharge to the aquifer is the principal raw water supply for southeastern Florida utilities, agriculture, and the Everglades.

The competition for water is acute during the dry season as irrigation demands exceed total rainfall and aquifer levels decline, resulting in saltwater intrusion problems. Saltwater has also been allowed to migrate inland through canals without salinity control structures, creating additional saltwater intrusion problems for eastern utilities. Saltwater intrusion results in the affected utilities being faced with restrictions on groundwater withdrawals permitted by SFWMD.

Hollywood responded to restrictions on its allocations by undertaking a long-term water supply plan that evaluated raw water needs. The city pursued an approach by diversifying its water supply through a bulk water purchase contract with Broward County. Both the city and county sources are supplimented with brackish water supplies obtained from the Floridan aquifer. However, both of these new water supplies require treatment beyond the lime softening treatment process currently employed by the city. As a result, the city undertook an upgrade of its water treatment process in order to accommodate the new water supplies.

Historical Perspective

The City of Hollywood has operated a water treatment facility that treats fresh, local groundwater since the late 1920s. Since then, the City has grown from a population of 2500 to over 130,000, accompanied by all the associated products of development - paved areas, canals for drainage, drainage piping, and structures that reduce the percolation of rainfall. The effect of this development is permanently reduced aquifer levels, which has contributed to the landward migration of saltwater.

The raw water supply comes form the Biscayne aquifer, about five miles from the Atlantic Ocean. Water quality in the Biscayne aquifer is generally good, with the exception of organic compounds and the presence of several types of bacteria. Chloride concentrations in the wellfield average 40 to 50 mg/L. Elevated levels of organic and tannic acids exist due to natural seepage of rainwater through the overlying confining layer. Treatment objectives must consider the problems created by iron and sulfur-reducing bacteria, which are protected by slime-producing bacteria.

In the early 1960s and the late 1970s, Hollywood constructed and expanded its water treatment facility with Spiractor treatment units to remove hardness. These units involve the discharge of

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water into the base of the conical-shaped units, the addition of lime, and the use of a sand catalyst, onto which calcium carbonate precipitates and adheres. Subsequent filtration and chlorination are included in the treatment process. Since the early 1980s, the city has had 37.5 MGD of treatment capacity in the Spiractor units, which produced good water quality but were projected to have difficulty meeting proposed trihalomethane standards.

In addition, when the city applied for renewal of its consumptive use permit from SFWMD in 1989 and again in 1994, the district reduced allowable groundwater withdrawals because of proximity of the city's wellfields to a saltwater canal, and also because of later findings by the city during its safe yield modeling, the district's modeling program, and the USGS's study of saltwater exfiltration from the canal and saltwater intrusion along the coast. The city's allocation was reduced from over 28 MGD to 20.67 MGD for all wellfields. More severe limitations were placed on the city's north wellfield (0.75 MGD), which contains 10 wells with 14 MGD capacity.

As a result, in 1990 Hollywood contracted for an assessment of its water treatment needs in the ensuing 20 years. The consultant recommended that the city explore water supply diversification options and that it construct a membrane process to augment or replace the current, aging Spiractor units. Since Broward County was investigating a raw water supply in the vicinity of Hollywood, a contract was secured for up to 8 MGD of raw water from the new county wellfield.

In addition, during this period the city drilled a test/production well into the Floridan aquifer. Investigative studies found that the well had artesian pressure at the surface, that plenty of water was available, and that total dissolved solids (TDS) levels of 2200 mg/L could be easily treated by low pressure reverse osmosis.

Heeding the consultant's recommendation to pursue multiple water sources, Hollywood decided to construct the new membrane process with both salt and freshwater components.

Design of Membrane Facility

The initial plan was to design a 30 MGD membrane facility consisting of 14 MGD reverse osmosis and 16 MGD membrane softening. Since a facility of this size was much larger than initially needed, only 14 MGD of membrane softening and 4 MGD of reverse osmosis membranes were proposed to be installed initially, with the intent to treat 4 MGD of the brackish Floridan water and the new county source, which the staff felt would be of poorer quality than the City's Biscayne wells.

The city required the consultant to design a facility that would treat water from all three sources, would provide the required water quality, and would make the product water from all three processes be compatible with one another. This included addressing the potential undersaturation of the reverse osmosis water by mixing it with lime softened water, prevention of significant deposition of hardness on pipes, and meeting all proposed SDWA requirements.

A pilot plant study was conducted to evaluate the operation of the proposed membrane design and to verify that the desired quality of treated water was achievable using the existing raw water supply from the Biscayne and Floridan aquifers.

The process flow schematics for membrane softening and reverse osmosis treatment both include pretreatment, membrane treatment, and post-treatment. However, there are significant design considerations that must be accounted for in low-pressure reverse osmosis processes. The process recovery rate for membrane softening is 85%, while the reverse osmosis system is estimated to produce a 75% recovery. The reduced recovery by the reverse osmosis process increases the quantity of raw water required to produce the same amount of permeate from one process skid, while producing a larger waste stream of concentrate.

The construction material for the raw water piping was stainless steel. The pipelines were installed above ground to allow for easier maintenance, field observation, and to avoid underground conflicts on the plant site. A scale inhibitor and sulfuric acid are injected into the water for stabilization before it flows into the cartridge filters. The design pH for the membrane softening process is 6.0, whereas the reverse osmosis system is designed for a pH value of 6.5.

Cartridge filtration is essential for removal of suspended particulates larger than five microns from the raw water. There are four stainless steel cartridge filters with over 300 40-inch elements in each. The cartridge filters were installed vertically to allow for ease in removing the covers. The maximum flow rate is between 2 and 3 gpm per element.

After the feedwater is chemically conditioned and suspended solids are removed, it is delivered to the stainless steel feed pumps. A dedicated feed pump supplying each skid increases the feedwater pressure prior to applying the feedwater to the membranes. The vertical turbine pumps were initially sized for the membrane softening process to deliver 1544 gpm with an operating pressure of 130 psi and 1740 gpm with an operational pressure of 400 psi for the reverse osmosis skids.

The configuration of the membrane skids accommodates three stages of softening membranes and two stages of reverse osmosis membranes. The skids are designed to hold 54 pressure vessels, each housing seven Hydranautics 8040-LSY-PVD1 membrane elements. The reverse osmosis system uses Hydranautics CPA2 membranes with a recovery rate of 75%.

After passage through the membrane skids, the reverse osmosis and membrane softening permeates are combined. The residual pressure allows the water to move the post-treatment processes, which consists of degasification and chemical addition. The permeate flowstreams contain hydrogen sulfide and carbon dioxide gases. While this amount is minimal in the Biscayne water, the Floridan aquifer supply contains about 3.5 mg/L of hydrogen sulfide. The degasifiers remove hydrogen sulfide from the permeate flow streams by forced-draft degasification. The initial design for the permeate flow stream requires two degasifiers. An odor control system is required for the removal of hydrogen sulfide produced by the permeate degasifiers. Two-stage, packed scrubbers with equally sized reaction vessels use sodium hydroxide and sodium hypochlorite for the odor removal process.

The post-treatment chemicals are sodium hydroxide, zinc orthophosphate, sodium silicofluoricle, ammonia, and chlorine. The chemical system equipment (pipes, valves, feed equipment, chemical storage) is designed to accommodate the feed requirements when the initial 18 MGD is expanded to 30 MGD. After chemical addition, the membrane process waters are combined with the lime softening water and pumped to on-site storage tanks and the distribution system.

The membrane cleaning/flushing system consists of cleaning and flushing solution tanks, 5-micron cartridge filters, and cleaning pumps. The cleaning pumps are constructed to handle high and low pH cleaning chemicals. The cleaning system is designed to accommodate future needs when the system is expanded.

A shut-down flush is required every time a membrane skid is taken out of operation. The raw water in the membrane elements is replaced with permeate water from the permeate flushing tank. The permeate is pumped through the membrane elements using the feed pump at low pressure. The permeate flushing system is designed to meet future design conditions.

Membrane treatment produces a waste stream commonly referred to as "reject water" or "concentrate," which EPA has classified as an industrial waste, thereby requiring the city to acquire an industrial wastewater discharge permit from DEP. Because the city's wastewater treatment plant currently disposes of treated effluent via ocean outfall, the city applied for a permit to discharge the concentrate in the same manner. After careful review and a predischarge testing program, the permit was issued in December 1997.

An evaluation of recycling the concentrate from the nanofiltration system through the reverse osmosis units was undertaken. Both waters were expected to have the same TDS (2200 mg/L), although the makeup of the nanofiltration concentrate would contain much more calcium than salt. High levels of fouling bacteria were also a concern (and remain so). The evaluation indicated that mixing the brackish Floridan water with the concentrate recycle would work, and the piping to accomplish this was installed. The recycle system has not yet been placed in service because of water quality problems in the Floridan system, but the city's water treatment facility will be the first to utilize this recycle mode idea. Its use will reduce the concentrate discharge by 1 to 2 MGD and will save the same amount of water.

The new treatment plant includes all facilities necessary to produce 18 MGD of finished water with the provision to later install the remaining units in currently available space. Most of the expansions can be accomplished with minimal effects on continuous plant operation. The facility also includes a central supervised computer system that allows operations staff to operate and monitor both the lime softening and membrane treatment process from one location. The computer system will allow operators to monitor the entire water distribution system, including the wellfields and tanks, and to monitor the wastewater system during storm events.

Construction

Construction began in the fall of 1993, raw water was introduced in the summer of 1995, and the facility was dedicated on February 5, 1996. The most difficult issues during construction were resolving control system integration problems and bacteria in the raw water coming into the plant. (See "Groundwater Treatment Needs for Membrane Treatment Processes" in this issue.)

The total cost of the facility, including engineering and concentrate disposal, was $23 million. Future expansion in 2-MGD increments will cost approximately $1.5 million each. The costs are among the most reasonable for all large membrane facilities in Florida and similar to what would be expected for more conventional treatment, yet the plant provides significant operator flexibility, improved water quality to customers, and a longer plant operating life. Annual operating costs of the three processes are $0.45, $0.52, and $0.75 per thousand gallons for the lime softening, membrane softening, and reverse osmosis, respectively.

Conclusions

The new membrane treatment process will help Hollywood meet its potable water demands for the next 20 years. The increase in plant capacity has allowed the city to explore the sale of high quality water to smaller, neighboring utilities, while solving water quality problems in its own system.

Using divided piping systems integrated into the plant, the facility can treat both freshwater and brackish water at the same time. It is one of the first in the world to install such capacity for both sources in one plant. Expansions can be made economically with minimal disruption to current operations. The costs are comparable to what would be expected for lime softening or similar treatment processes, and therefore do not adversely impact users. Costs will be stable over the long term. ■

Groundwater Treatment Needs for Membrane Treatment Processes

Frederick Bloetscher, Gerhardt M. Witt, Anne E. Dodd, and Christopher P. Dodd

Hollywood first experienced severe problems with its wells during the 1995 expansion of its water treatment plant. Microbiological testing indicated the presence of many species of bacteria and fungi, but a complete absence of algae. Severe and extensive corrosion damage was noted on all metal, including steel well casings, pipes, pump bodies, and fittings. It was determined that the environment within the aquifer causes biological organisms to be extremely aggressive toward ferrous materials, including Type 304 and Type 316L stainless steel.

A study of the problem indicates a symbiotic relationship between anaerobic bacteria and aerobic iron and slime bacteria. The organisms colonize in the formation, bore hole, well casing, pump column pipe, pump bowls, and motors, forming a stable but highly corrosive environment that facilitates failures of steel column pipes within one to two years in new installations, and of stainless steel pipes in less than one year. Concerns about corrosion extend from the wells to the raw water distribution lines and into both the lime softening and membrane treatment plants.

To address the problem, Hollywood has embarked on a program to minimize the impact of the bacteria and fungi. The program includes routine monitoring, revised material specifications, pump change-outs, initial and routine disinfection of the wells, replacement of steel and stainless steel parts, and slip-lining, abandonment, and drilling of new wells utilizing different materials.

The rock strata that underlie Hollywood allow significant quantities of groundwater to be withdrawn from the highly productive Biscayne aquifer. The aquifer, with maximum depths in excess of 280 feet below land surface and a top elevation averaging 5 feet above mean sea level, consists of interfingered vugular limestone, calcareous sandstone, and dolomitic limestone formations. The limestone has a tremendous capacity for the storage and movement of fresh water (aquifer porosities of 50 percent). It is generally recharged via summer rains but, to an extent, also by lateral movement from zones with higher piezometric heads — manmade and natural lakes and canals and the general movement of groundwater to the southeast from the eastern Everglades, which coincides with the western extent of the Biscayne aquifer. Rapid recharge is also enhanced by vertical solution channels in the overlying formation. However, where water levels decrease from man-induced drainage along the coast, the natural groundwater gradient has been modified and saltwater intrusion has become a problem.

The city currently has its own wellfields: one north and one south of the water treatment plant, both with production zones at a depth between 60 and 100 feet below land surface. The wells produce between 1 and 3 MGD, each with one to three feet of drawdown.

Twenty wells, up to fifty years old, form the city's wellfields. With the exception of the two newest wells, which are cased with polyvinyl chloride, the wells are primarily of steel construction. The raw water contains slight amounts of hydrogen sulfide and organic constituents. The color of the current raw water supply is generally under 30 color units.

Because the city's consumptive use permit, as issued by SFWMD, reduced withdrawals from 28 to 20.67 MGD in the Biscayne aquifer to address the saltwater intrusion concerns, the city contracted with Broward County to provide up to an additional 8 MGD of raw water from the county's new Brian Piccolo Wellfield, located ten miles west of the city's wellfield, to assist the city in meeting its raw water demands. However, the county's raw water has a high color (80 to 100 c.u.) and organic content, typical of more western wellfields in Broward County that are influenced by the Everglades wetlands system. Therefore, as confirmed by a study performed by the county, the traditional lime softening treatment system previously utilized by Hollywood would not be able to treat the water adequately to meet state and federal standards for trihalomethane formation. The color concern meant that the raw water from the county would need to be treated by a membrane softening system.

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Hollywood currently operates a 37.5 MGD lime softening facility that uses Spiractor treatment units with a sand catalyst to treat relatively good quality Biscayne aquifer water. In 1995 the city completed construction of a 30 MGD membrane treatment plant to augment its existing system. The plant was designed to house 16 MGD of softening membranes to treat Biscayne aquifer water (currently 14 MGD is installed) and 14 MGD of reverse osmosis membranes to treat the brackish raw water of the Floridan Aquifer System. Currently, reverse osmosis membranes capable of handling 4.0 MGD are installed on the same site as the lime softening system. All three treatment process product waters are combined together to produce high quality, potable water that exceeds all state and federal standards.

Evaluation of Water Quality and Well Failures

In overseeing the operation of Hollywood's Biscayne aquifer wells, the city's water plant operators routinely address electrical motor problems caused by lightning or age, or problems due to excessive drawdowns. However, these problems were often not fully investigated and/or understood. Over the years, the city has experienced some well failure problems, most of which were blamed on age and wear on the system and which appeared to be little more than simple galvanic corrosion problems associated with an aggressive raw water. When problems such as submersible pumps and motors corroding and falling to the bottom of the wells occurred, repairs were made, including changing column pipe material from mild steel to stainless steel or fiberglass, in a non-systematic manner. Because the lime softening spiractor plant operated within the design parameters, and because finished water quality met or exceeded state and federal potable water standards of the Safe Drinking Water Act, no further investigations into well failures were performed.

As a result of the membrane water treatment plant construction, and based on experience in other jurisdictions and private entities, the city reviewed the water quality and chemistry in all of the city's wellfields and reviewed past well failures. Analysis of recent well failures by qualified engineers, hydrogeologists, and biologists found that the steel column pipes showed significant corrosion, deterioration, and leaks. In addition, general water quality and chemistry has deteriorated. Analysis of the corrosion damage and of the raw water indicated that a portion of the corrosion problem was caused by the use of stainless steel line shafts and/or bronze stabilizers (spiders) with the steel column pipe, thereby setting up a series of cathodic reactions that were enhanced by chemically aggressive waters and microbiological action.

Several fiberglass column pipes installed to correct corrosion problems had a bright orange slime layer when withdrawn from the wells after several years. The slime was caused by an iron bacterial growth consistent with the presence of *Sphaerotilus natans* and *Pseudomonas* species. In two separate instances, no observable damage was evident to the fiberglass, but in two wells, the pumps and motors corroded off and fell to the bottom of the boreholes. Upon retrieving the pump and motor, the stainless steel coupling showed severe corrosion.

Water samples were collected from both raw and potable water and analyzed for heterotrophic, fecal, and total coliform bacteria; fungal plate counts; and identification of fungal, bacterial, and algal species. According to industry standards, the presence of coliform bacteria is an indicator of a sanitary hazard, usually an indicator of fecal contamination. However, the identification of genera and species of bacteria that are known pathogens, and/or opportunistic pathogens is not routinely performed. Some bacterial, fungal, and algal species are known to plug membranes. The membrane process also concentrates the microbes in the reject water during treatment. This can be of significant concern if the point of discharge of the reject water is a surface water body, or a surface discharge such as spray irrigation where humans may be exposed to the water.

The investigation indicated that the wells contained significant quantities of not only *Gallionella* sp., *Sphaerotilus natans,* and other iron bacteria that had propagated on the stainless steel materials, but also anaerobic bacteria that had developed a symbiotic relationship with the aerobic iron bacteria species. The bacterial sampling data indicated the presence of slime-forming bacteria at virtually all sample sites, including the wells, raw water lines. and membrane trains, plus various species of other bacteria and fungi. Some *Pseudomonas* species are opportunistic pathogens to humans (specifically *Pseudomonas aeruginosa*). *Pseudomonas aeruginosa* was detected in the permeate, the wells, and in the raw feed water.

Further investigations were made at the membrane treatment plant. Iron bacterial staining and pitting were found on the stainless steel piping used for the raw water line on the plant site even during initial testing prior to plant start-up, and on the membrane intakes. Testing of the cartridge filters also showed effects from the bacteria, which cause rapid changes in differential pressures across the filters.

Bacteria Significance

The microbiological accumulations in raw water systems pose several significant concerns. First, in most water supply wells, the presence of slime-forming bacteria and iron-bacteria can clog the pore spaces in the formation and in the well screen and gravel packs. However, the Biscayne aquifer units are so transmissive that clogging rarely occurs. In addition, none of the city's wells are screened. This same blessing of high yield, though, adds to the mobility of bacteria within the aquifer so not only can they be transmitted from well to well through pipelines or improper valving, but they can also move directly through the formation. Second, the accumulations on the metallic surfaces create anodes (and therefore cathodes) and, in conjunction with reactions caused by dissimilar metals, can lead to steady deterioration over varying periods of time. *Pseudomonads* are acid formers, which makes ferrous materials particularly vulnerable to deterioration, especially in the presence of iron bacteria.

Pseudomonas sp. are adhering bacteria capable of producing a polysaccharide matrix (biofilm). They can permanently affix themselves to even laser-polished 316L stainless steel in a matter of minutes; attachment to steel or lower grades of stainless steel is easily accomplished. The biofilms can act as a barrier, protecting the bacteria incorporated in the films from disinfectants and oxygen and from the shearing effect of turbulent flow. Because the colonies are so extraordinarily difficult to eliminate, the best strategy is to control them by routine disinfection at the wells.

The microorganisms pose a significant fouling concern for both the membrane softening and reverse osmosis membranes, and they could lead to some breaching of the membranes, whereby the organisms could subsequently enter the distribution system. Because of the size of the openings in the membranes (0.45 microns), it has been assumed that the membranes would filter out the bacteria. However, for three significant reasons this is not always the case. First, while most bacteria are between 0.5 and 2.0 microns in length, some may be less than 0.45 microns wide. Second, the o-ring seals connecting the membranes allow some leakage, allowing the permeate to be exposed to the raw water. Third, under certain conditions the bacteria may go into a micro-encapsulation phase and be significantly smaller by several orders of magnitude than their normal state.

Experience in other membrane water treatment plants indicated that the failure to treat the problem at the wells would result a significant quantity of bacteria being passed into the membrane units, causing a fouling problem that would require extensive cleaning with a blocide (bisulfite), citric acid, or hydrogen peroxide, or a combination thereof. Use of chlorine is the most common solution to bacteria removal in raw water. Because the water plants use membranes that are not chlorine tolerant, any such treatment would have to occur at the well with appropriate safety precautions to assure that the chlorine would not damage the membranes.

While the potential for clogging the membrane plant is a significant concern from an operational perspective, the potential for breaching the membrane system and allowing the bacteria to pass through into the distribution system has more ominous consequences. Also, the concentrated reject water contains a bacterial concentration on the order of three or four times the native concentration, which would enhance corrosion throughout the concentrate pipe and pumping systems (inclusive of injection well disposal). Dependent on the treatment of the concentrate (if any), and the point of discharge, there exists a potential detrimental effect on aquatic life and humans.

Analyses indicate that the lime softening process does a relatively good job of removing bacteria because of the mixing of lime and raw water and the adherent characteristics of the bacteria. However, corrosion of the steel pipe at a lime softening plant could also be partially attributed to the bacteria being brought in with the raw water.

Addressing The Biocorrosion Problem

Because the bacterial counts in Hollywood's Biscayne and Floridan aquifer wells, and the county's wells were found to be high (in some cases greater than 10,000 Colony Forming Units per 100 milliliters [CFU/100 ml]), some form of treatment was warranted. As a result, the city accepted bids to clean all of its wells with chlorine, acid, and scrubbing processes (the county proposes to use the same contractor). The program consisted of hydraulic jetting of the 2-inch thick slime/iron bacteria encrustation of the casing with calcium hypochlorite, and acidizing the wells with sulfamic and hydrochloric acid. The city instituted a routine disinfection program of 6,000 ppm calcium hypochlorite on a monthly basis. The pH in the water during superchlorination and acidization ranged from 12 to under 1. The program significantly reduced the presence of microorganisms, in most cases to yield an HPC of 0 CFU/100 ml. An experimental process using hydrogen peroxide was tried on a limited number of wells. The results are still under review.

In addition, a program was planned to rehabilitate some steel cased wells by sliplining them with PVC, and to abandon others, replacing them with new PVC-cased wells. The ten oldest, smallest-diameter wells were designated for abandonment. Lining would have resulted in a loss of capacity and an increase in uphole velocity beyond that recommended for membrane systems (2.5 feet per second - Witt et al). All of the pumps are proposed to be changed from steel or stainless steel to bronze, and six new PVC wells with bronze pumps will be installed. All column pipes will be fiberglass. The estimated cost is $5.7 million.

Conclusions

Long-term microbiological problems may go unnoticed, undiagnosed, or improperly diagnosed, especially if a utility is not utilizing a membrane process. Cathodic reactions from dissimilar metals pose significant risk to the long-term maintenance of the wellfield and may be enhanced and exacerbated by microbiological action. A complete investigation and proper analysis of the raw water supply, including silt, sand, colloidal particles, clay, and microbiological analyses, are required prior to design of membrane processes. Considering the intolerance of membranes to chlorine, bacteria that were previously not a treatment or post-treatment concern may become a significant concern.

Routine monitoring of background bacteria, especially iron and slime-producing species, should be performed by all utilities, whether water is obtained from a groundwater or a surface water source. The presence or relative absence of microorganisms should determine the frequency of testing. If undesirable bacteria are found in wells, distribution system sampling should occur routinely.

The significant issue of microbiological activity is generally ignored by design engineers, construction engineers, and contractors, leaving the operations staff with a problem shortly after startup of the facility. All parties must understand that as utilities move toward more advanced treatment methods, more knowledge must be gained about the quality of the raw water. It is recommended that utilities in the process of designing or constructing new production wells or plants study the raw water quality, potential plugging and fouling problems, and the geologic formations prior to completing design and construction. A multidiscipinary approach to the process design is required, and it should include a competent hydrogeologist and a microbiologist, as well as engineering professionals. Test wells should be checked for microorganisms and clay, colloidal, sand, and silt production.

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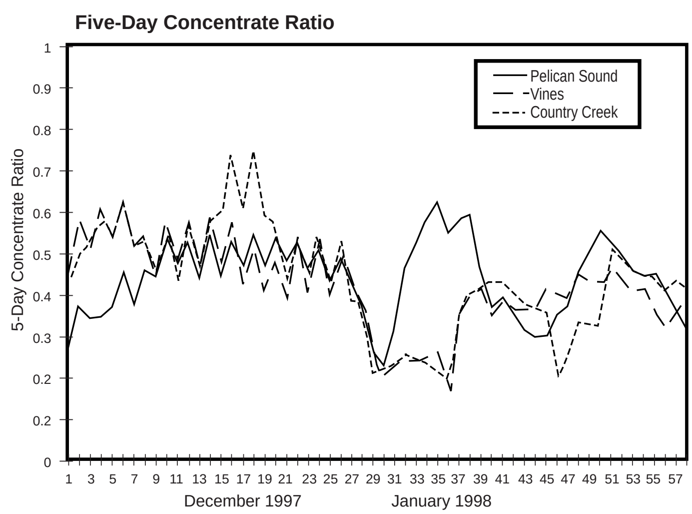
off-site effluent pumps. The SCADA system monitors the operation of the effluent pumps at the plant. When the off-site effluent pumps are set to pump to the reuse sites, the SCADA system stops the concentrate pumps and sets the flow control valves at the reuse sites to predetermined positions. At the end of the effluent pumping cycle, the operator switches to on-site storage, and the SCADA system starts the concentrate pumps and resets the flow control valves at the reuse sites to new, predetermined positions. Starting the concentrate pumps draws down the level in the wet well and opens the supply valve between the concentrate storage tank and the wet well. Normally, no operator action is required for routine reuse system operation.

The system can be programmed to control flow rates at each site by local flow control, although this is not feasible at present flow rates. The mode of operation in use is balancing flows by remotely setting valve positions from the operations center where the SCADA system displays flows, totalized flows, pressures, conductivities, and control valve positions at each site. The operator enters valve openings for each of the three reuse sites for the following cases: one concentrate pump operating: two concentrate pumps operating; one effluent pump operating: two effluent pumps operating. Once these values have been determined and entered, the SCADA system will automatically implement these settings until new values are entered by the operator. Total daily flow limits can also be entered for a particular site; when these limits are reached. the valve at that site automatically closes.



The accompanying graph shows the concentrate flow as a fraction of total flow for each site on a five-day moving interval for the December 1997 through January 1998 period. The five-day interval corresponds to the length of a typical cycle. The main operating objective for the system is to deliver the same overall blend to each reuse site, and the graph indicates that the trend lines generally move in unison. The graph also shows that the overall ratio during the period was approximately 60% effluent/40% concentrate instead of the historical yearly ratio of 70/30. That is caused by the relatively high water demands on the system during those months. ■