Energy Research and Development Division
FINAL PROJECT REPORT

RECLAMATION OF WASTEWATER FOR COOLING TOWER OPERATIONS

Prepared for: California Energy Commission
Prepared by: Gas Technology Institute

November 2014
CEC-500-2015-040

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Contract Number: PIR-10-021

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ACKNOWLEDGEMENTS

GTI would like to thank the California Energy Commission and its project partner Gills Onions for their support and cooperation.

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*Reclamation of Wastewater for Cooling Tower Operations*Project Grant Number PIR-10-021, conducted by Gas Technology Institute. The information from this project contributes to Energy Research and Development Division's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

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ABSTRACT

This grant demonstrates the effectiveness of a commercially available membrane filtration technology to clean and reuse wastewater produced from the Gills Onions onion processing plant (the world's largest year-round grower and processor of fresh-cut onions) for supplying evaporative cooling towers used in the plant. This process enabled a reduction in demand for fresh city water by up to roughly 50,000 gallons-per-day, decreasing volume impact on the sewer system and reducing water conveyance energy demands (energy associated with delivering water to and carrying wastewater from the onion processing plant).

Keywords: Cooling towers, filtration, Gills Onions, MBR, membrane bioreactor, membrane, MF, microfiltration, nanofiltration, NF, SBR, sequencing batch reactor, UF, ultrafiltration, wastewater

Please use the following citation for this report:

Hill, Andy; Hayes, T., Sishtla, C. (Gas Technology Institute). 2014. ***Reclamation of Wastewater for Cooling Tower Operations.*** California Energy Commission. Publication Number: CEC-500-2015-040.

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EXECUTIVE SUMMARY

Introduction

The food processing industry is composed of canners, freezers, dehydrators, and fresh-cut operations. Agriculture remains the largest industry in California, and the subset of food processing requires significant amounts of water. California continues to suffer from its perennial drought and must find creative ways to source and reuse water. Recycling water is typically a lower-cost/energy alternative to other new sources of fresh water like desalinization. Because current law prohibits the use of recycled water for food contact, it is the goal of this project to explore reusing water for other purposes, specifically for supplying evaporative cooling towers.

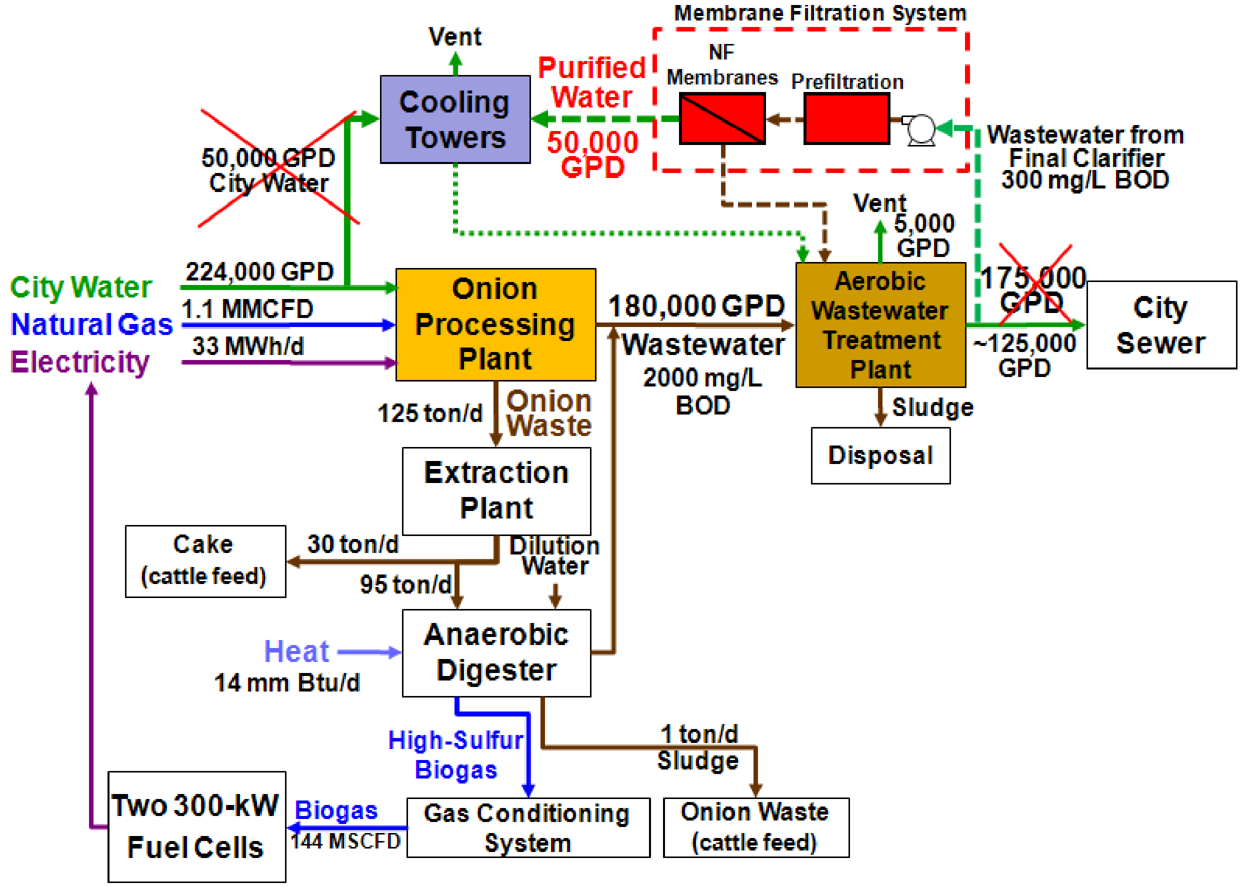
There is a large potential market for technology to produce recycled water for supplying cooling towers in the food processing industry. California's fresh produce industry harvested around 24 million tons in 2008, of which about 20 million tons are chilled from roughly 78° to 38°F. The chilling required to accomplish this is roughly 1.6 trillion British thermal units (BTUs). As it requires about 1,000 BTUs to evaporate a pound of water, this equates to about 1.6 billion pounds of water or roughly 200 million gallons of water. Based on a recent industry study the average water utility electricity used to produce and deliver 1,000 gallons of water is about 2-14 kilowatt hours (kWh), depending on location. Delivery of this cooling tower water represents a total electricity requirement of 0.4 gigawatt hours (GWh) to 3 GWh, much of which could potentially be saved by applying the proposed water reuse system.

Gills Onions, located in Oxnard, California, is the largest fresh onion processor in the nation. The company processes more than 200 million lbs of onions a year and uses large amounts of water during nearly every stage of onion processing and in everyday operations. Fresh city water is used to rinse, clean, and transport onions between processes and is added continuously to both the cooling towers and the biodigester to supplement onion juice and reduce foaming. Gills Onions uses an onsite aerobic wastewater treatment plant to treat its effluent before it is disposed of into the city of Oxnard's sewer system.

The existing flowsheet of the Gills Onions plant presents a very good opportunity for water reclamation and energy conservation (Figure ES-1). About 180,000 gallons per day of wastewater flow from the plant to an extended aeration treatment system that effectively uses oxygen from the air to oxidize organic matter in wastewater and reduce the biochemical oxygen demand from around 2,000 to about 300 milligrams per liter (mg/L), representing an 85 percent decrease in soluble organics. A minor portion (roughly one-quarter) of the effluent flow would be sufficient to meet the water demand of the cooling towers if the water could be conditioned to avoid fouling of the heat exchanger equipment.

The wastewater treatment effluent requires treatment (polishing) to meet the specifications for the cooling tower influent that are consistent with the manufacturer recommendations for biofouling and corrosion control. Removing both microbes and biochemical oxygen demand from the wastewater can be achieved through the membrane filtration technology.Various types of membrane filters are used in many industrial processes to achieve useful separations of solutions containing microbes and soluble organic matter.

Figure ES-1: Existing Flowsheet of the Gills Onions Plant



(Showing the Membrane Filtration System)

At the Gills Onions aerobic treatment plant, it is highly probable that efficient removals of microbes and residual biochemical oxygen demand may be achieved through inexpensive microfiltration/ultrafiltration (MF/UF) or nanofiltration (NF). These types of membrane filters are used in many industrial processes to achieve useful separations of solutions containing microbes, ionic species and soluble organic matter. Membrane filters are pressure driven processes that achieve separations of constituents through size exclusion and are usually classified by ranges of applicable pore sizes and molecular weights of constituents that are allowed to pass. Nanofiltration is a fairly recent development in the area of membrane separation processes. Similar in terms of membrane chemistry to UF/MF, in contrast, nanofiltration allows the passing of certain ionic solutes (such as sodium and chloride), predominantly monovalent ions, as well as water. Larger ionic species, including divalent and multivalent (scale-forming) ions, and more complex molecules are highly retained. If a low-cost process can be economically applied to the removal of bacteria and organics from effluent of the aerobic treatment plant, as shown in the hatched area of Figure ES-1, this stream could easily be used to satisfy the substantial water demand of the Gills Onions cooling towers. This proposal outlines a stepwise approach for determining the technical, practical, and economic feasibility of applying commercially available membrane technology to convert clarified effluent from the aerobic treatment plant to a water stream suitable for reuse as a cooling tower feedstream. At the Gills Onions processing plant, this achievement would allow the plant to save roughly 15,000-50,000 gallons per day of water and wastewater requiring final discharge to the sewer.

Commercial membrane filtration is used worldwide in the chemical and biotechnology industries to concentrate streams and maintain product quality in manufacturing. It has also been established as a viable and economical means of filtering and cleaning wastewater and industrial process water for discharge, irrigation, or other reuse options. Although this technology is becoming increasingly common in municipal water and wastewater treatment, the proposed project will demonstrate the cost and energy effectiveness when applied to the scale and waste streams in food processing. Operational data are necessary to demonstrate the application of this technology in the California food processing industry for proving the potential of the technology to save the state's precious water and reducing water conveyance energy demands. It appears that no food processing plants in California are using membrane filtration of wastewater for reuse.

Project Purpose

This project demonstrated using a commercially available membrane filtration system to clean and reuse wastewater produced in the Gills Onions plant for use in the evaporative cooling towers, and to quantify the water/wastewater reductions and energy savings of this technology. The metrics to attain these goals are acceptability of water quality from the membrane filtration system for supply to the cooling towers and determination of the amount of water/wastewater reductions and energy savings realized during the demonstration. This will reduce demand for fresh city water, decreasing volume impact on the sewer system,

The above objectives will be accomplished by:

- Implementation of an enhanced aerobic treatment consisting of the aeration basin followed by an aerobic sequencing batch reactor to provide added soluble organics removal followed by a sequence of filtration consisting of rough filtering, ultrafiltration, and nanofiltration.
- Identification and procurement of a pilot-scale membrane filtration system.
- Operation of the pilot membrane filtration system at the Gills Onions site (for up to 900 hours), using flow rates of roughly 5 gallons per minute to demonstrate a water quality acceptable for the cooling tower use per criteria listed in .
- If pilot system water quality meets quality criteria, then scale-up and procure a membrane system for full-scale demonstration. Operate full-scale membrane system for up to 200 hours at flow rate of up to 10-35 gallons per minute (15,000-50,000 gallons per

day) to demonstrate water production for meeting cooling tower requirements. Quantify water/wastewater savings and energy savings from the operational data.

Project Results

The positive results obtained suggested that the membrane filtration system functioned as expected to attain target specifications set for the water to feed the cooling towers. This was confirmed through analyses performed of the pilot-membrane permeate (product water) and results from the full-scale membrane filtration demonstration testing.

Results from both the pilot (190-hours of operation) and the full-scale membrane units indicated the following useful outcomes:

- Further treatment of the effluent of the aerobic biological reactor with ultrafiltration followed by nanofiltration showed that a substantial removal of organics was achieved with the nanomembrane, reducing the total organic carbon (TOC) by more than 67 percent. This represents a further polishing of the effluent of the biological treatment unit and provides a good control on residual carbon to levels acceptable for reuse as a cooling tower feedwater (TOC < 10 mg/l).
- The ratio of BOD to TOC increased significantly (by a factor of 1.8 to 10) as the treated wastewater stream passed from the influent to the permeate side of the nanofilter. This observation would infer that the larger, more refractory organic molecules are rejected by the membrane. In an integrated process flowsheet, the reject stream from the nanofilter can be recycled to the influent end of the aerobic reactor for further biological breakdown of the slower-to-degrade refractory organics.
- Significant demineralization of wastewater was achieved with the nanofiltration step, causing the salinity to be decreased from nearly 3,600 μmho (reciprocal of resistance) to an average of about 2,500 μmho or less, thereby enabling the effluent water stream to practically meet the specifications for cooling tower salinities.
- Substantial reductions in hardness of nearly 90 percent were achieved, causing harness to decline from around 440 down to about 50 mg/l as calcium carbonate; most of this decline of hardness was due to the removal of calcium and magnesium ions. This process performance enabled the wastewater stream to become compliant with the hardness criteria for the cooling tower.
- No significant fouling of the nanofiltration membranes was observed; a low and stable pressure drop of about 40 per square inch or less was maintained across the entire operational periods for both pilot and full-scale nanomembrane demonstration systems.
- The above multipurpose treatment capabilities were achieved by the nanomembrane treatment train at energy costs that are less than $0.25/1000 gallons.

Project Benefits

The California Energy Commission estimates that in California 19 percent of electricity use, 30 percent of nonpower plant-related natural gas, and 86 million gallons of diesel fuel are consumed annually for water-related uses. Within the region where Gills Onions is situated, much of the incremental water demands will be addressed through the Southern Delivery System, which transports water using about 4.63 MWh per acre ft (14.2 kWh/1000 gallons) of water delivered.

On the other hand, the applying nanofiltration to industrial water streams requires roughly 2 kWh/1000 gallons. Preliminary filtration tests on the Gills Onions effluent water have resulted in pressure drop and water flux data consistent with the literature value of 2 kWh/1000 gallon energy requirement. If ultrafiltration is sufficient for satisfactory cooling tower operation, pressure drop requirements would be reduced by more than half, and the energy requirement would fall to less than 1 kWh/1000 gallons. If total energy requirements for upgrading the Gills Onions water for reuse in the cooling tower reached a total of 3 kWh/1000 gallons, an energy savings of nearly 80 percent would be realized when compared to the incremental energy costs of transporting water to the Oxnard region using the Southern Delivery System.

Similar results can be achieved at hundreds of food processing and beverage facilities across California to provide low cost treatment of effluents to generate water feed streams for on-site cooling tower operations and achieve significant electricity savings in water conveyance. Water conservation through recycling is an important contribution in the effort to reduce the energy footprint of industry, thus easing the strain on infrastructure and peaking generators and reducing the overall costs of electricity charged to the ratepayer.

CHAPTER 1: Introduction

1.1 Project Goals

This project demonstrated using a commercially available membrane filtration system to clean and reuse wastewater produced in the Gills Onions plant for the evaporative cooling towers, and to quantify the water/wastewater reductions and energy savings of applying this technology. The metrics set to attain these goals are: acceptability of water quality from the membrane filtration system for supply to the cooling towers and determing the amount of water/wastewater reductions and energy savings realized during the demonstration. This will reduce demand for fresh city water, decreasing impact on the sewer system while contributing to the goal of water conservation and sustainable water management in California.[1] These objectives were accomplished by:

- Implementing an enhanced aerobic treatment consisting of the aeration basin followed by an aerobic sequencing batch reactor (SBR) to provide added soluble organics removal followed by a sequence of filtration consisting of rough filtering, ultrafiltration (UF) and nanofiltration (NF).
- Identifying and procuring a pilot-scale membrane filtration system.
- Operating the pilot system at the Gills Onions site (for up to 900 hours) using flow rates of ~5 gallons per minutes (GPM) to demonstrate a water quality acceptable for the cooling tower use per criteria (Table 1).
- If pilot system water quality meets quality criteria, then scale-up and procure a membrane system for full-scale demonstration.
- Operating full-scale membrane system for up to 200 hours at flow rate of up to 10-35 GPM (15,000-50,000 gallons per day) to demonstrate water production for meeting cooling tower requirements.
- Quantifying water/wastewater savings and energy savings from the operational data.

[1] Association of California Water Agencies. 2009. “Water for Tomorrow.” Onward Publishing, Inc., New York.

Table 1: Recirculating Water Chemistry Guidelines for the Gills Onions Evapco Cooling Towers

Property	Range
pH	6.5 to 8.3
Hardness as CaCO3 (ppm)	50 to 300
Alkalinity as CaCO3 (ppm)	50 to 300
Total Suspended Solids (ppm)	<25
Bacteria Count (cfu/ml)	<10,000
Conductivity (Micro-mhos/cm)	<2,400 micro-mhos
Chlorides as Cl (ppm)	<250
Chlorides as NaCl (ppm)	<410
Sulfates (ppm)	<250
Silica as SiO2(ppm)	<150

Source: http://www.evapco.com/sites/evapco.com/files/white_papers/113AA-Ops-Maint.pdf

1.2 Project Approach

1.2.1 Project Organization

GTI led the project and Gills Onions in Oxnard, California, partnered with GTI. Gills Onions provided pilot and full-scale membrane systems for testing and demonstration.

1.2.2 Technical Approach

The project designed, procured and implemented the pilot and full-scale membrane systems to obtain desired water quality to feed the cooling towers in the existing plant by:

- Devising a scheme for pilot- and full-scale demonstration testing based on existing processing assets at the Gills Onions plant, specifically addressing integration of the biological and membrane processes.
- Identifying and procuring a pilot-scale membrane filtration system: for operation prior to the demonstration of the full-scale membrane filtration unit. This approach determined compatibility of one or two promising filtration systems to enhance the probability of success of the follow-on full-scale demonstration effort.
- Performing Qualification Testing of the pilot membrane system: installing and operating the pilot membrane filtration unit on a portion of the effluent of the final clarifier of the activated sludge system for a total of approximately 500 hours to obtain data for scaleup of the membrane system for demonstration.
- Scaleup and procuring membrane system for demonstration: performing engineering and scaleup of the optimum membrane system determined to accommodate flow requirements of the cooling towers.
- Demonstrating full-scale membrane system: preparing the site, procuring, installing and commissioning the full-scale membrane system and operating for up to 200 hours for testing.

1.2.3 Project Implementation

GTI devised and assisted Gills Onions with a scheme using an aerobic biological SBR to consistently provide a treated water feed with acceptable biochemical oxygen demand (BOD) and chemical oxygen demand (COD) levels of <100 mg/L for testing of a membrane filtration system. This involved implementing an enhanced aerobic treatment consisting of the aeration basin followed by an aerobic SBR to provide added soluble organics removal followed by a sequence of filtration consisting of rough filtering, ultrafiltration (UF)/microfiltration (MF) and nanofiltration (NF).

Gills Onions procured pilot- and full-scale membrane filtration systems for installating and testing, and performed water analyses to demonstrate acceptable quality for feeding cooling towers.

CHAPTER 2:
Existing Gills Onions Processing Facility

2.1 Background

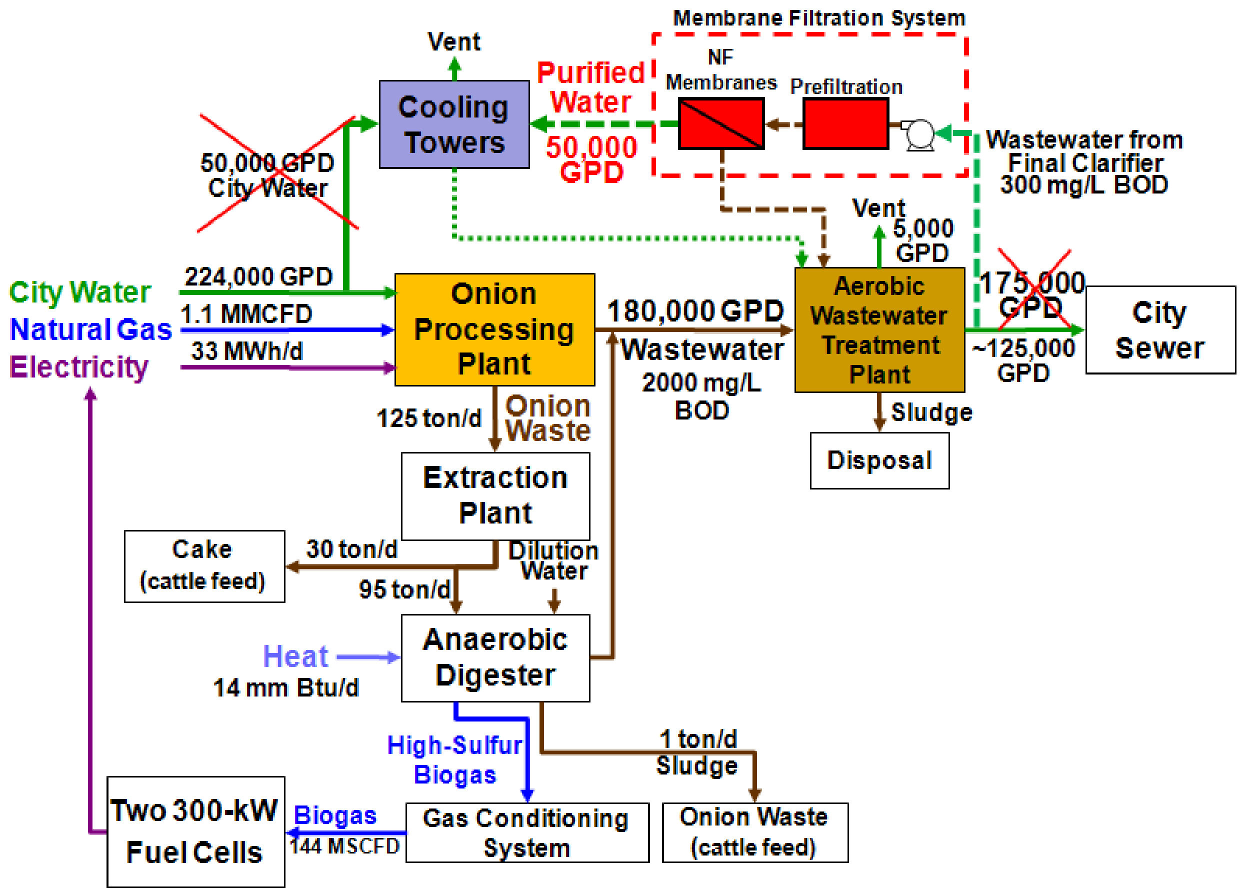
Gills Onions, located in Oxnard, California, is the largest fresh onion processor in the nation. The company processes more than 200 million lbs of onions a year and uses large amounts of water during nearly every stage of onion processing and in everyday operations. Fresh city water is used to rinse, clean and transport onions between processes and is added constantly to both the cooling towers and to the biodigester to supplement onion juice and reduce foaming. Gills Onions ues an onsite aerobic wastewater treatment plant (WWTP) to treat its wastewater before it is disposed of into the city of Oxnard's sewer system.

The existing flowsheet of the Gills Onions plant presents a very good opportunity for water reclamation and energy conservation (Figure 1). About 180,000 GPD of wastewater flow from the plant to an extended aeration treatment system that effectively utilizes oxygen from the air to oxidize organic matter in wastewater and reduce the biochemical oxygen demand (BOD) from around 2,000 to approximately 300 mg/L (milligram/liter), representing an 85% decrease in soluble organics, consistent with the performance of the process described in the literature.[2,3] A minor portion (approximately 1/4th) of the effluent flow would be sufficient to meet the water demand of the cooling tower if the water could be conditioned to avoid fouling of the heat exchanger equipment.

[2] Metcalf & Eddy, Inc. 1972. Wastewater Engineering. McGraw-Hill Book Company, New York, NY.

[3] Rudolfs, W. 1953. Industrial Wastes. p. 51-86. Reinhold Publishing Corp., New York, NY.

Figure 1: Existing Flowsheet of the Gills Onions Plant



Showing the Membrane Filtration System

2.2 Rationale for Water Reuse

At the most basic level of community water planning in California, the reason for conducting this project is to determine the technical and economic feasibility of upgrading vegetable processing wastewaters (using the Gills Onions Facility as the example) to a water stream that is of sufficient quality to be used for feed water for the cooling tower, thereby achieving substantial reduction in demands on the community water supply and achieving energy savings through water conservation that reduces the incremental need for future water supplies procured through long distance water conveyance.

In its website (http://publicworks.cityofoxnard.org/14/99/478/), the City of Oxnard explains that the city's water supply consists of a mixture of three sources that include groundwater from local City of Oxnard wells, imported water from the United Water Conservation District (UWCD), and imported surface water from the Calleguas Municipal Water District (CMWD). Since two out of the three water sources are conveyed more than 20 miles into the Oxnard vicinity, and since the most constrained water source is likely to be local groundwater well sources, it is clear that reducing water demands at the Gills Onions facility by 15,000-50,000

GPD provides benefits primarily through displacement of water piped long distances from outside of Oxnard.

This consideration underscores a situation where water reuse can potentially result in significant energy savings in addition to substantial water conservation. At the Gills Onions facility, such savings would depend upon the ability to achieve the upgrading of the effluent at a reasonable input of electricity and at reasonable overall treatment costs represented by capital and operating costs. For this reason, the treatment processing to meet any objective leading to water conservation at industry sites needs to be carefully selected, designed and operated to minimize the capital and operating costs associated with upgrading water streams for the purpose of reuse if a net energy and/or cost savings are to be realized. This was the direction pursued in this project conducted at the Gills facility.

Wastewater from the Gills Onions operation is generally characteristic of effluents generated by many vegetable processing operations. Clean water is essentially a tool complimentary to the equipment used to wash and clean vegetable products, perform housekeeping functions, and convey wastes from food receiving and preparation floor areas to the plant drainage system. Since large amounts of water are used in the operation, many of the plant effluent water streams are at moderate concentrations of organic and inorganic constituents. Across the U.S., onion processing generally produces an effluent stream containing a BOD_5 of 1,000-2,000 mg/L and total suspended solids (TSS) of about 175-1030 mg/L[4] and the raw wastewater from the Gills Onions facility is usually consistent with these ranges.

As is performed at many vegetable processing facilities, the main raw wastewater stream at Gills Onions is subjected to primary treatment for suspended solids reduction using sedimentation and/or flotation followed by secondary treatment using extended aeration. In the extended aeration process, oxygen – through the delivery of air through spargers – is introduced into the fluid contents containing active bacteria that use oxygen to convert organic matter to carbon dioxide and inert materials; this type of processing is often referred to as aerobic treatment. In operation, wastewater from the primary settlers is fed to the aeration basin at a continuous flow. At the Gills Onions facility this flow may be variable, but hydraulic retention times are usually greater than six hours and may extend to more than 12 hours. The performance of the aerobic treatment process shows that the extended aeration process is capable of achieving effluents with a BOD_5 of 300-500 mg/L, a reduction of 75-85 percent from influent values of 1000-2000 mg/L of BOD_5 (Figure 2).

In examining the Gills Onions flowsheet for wastewater management, it was recognized early on that the existing in-place processes had value in achieving the removal of most of the total suspended solids and more than 80% of the soluble organics (BOD_5) from the waste stream. In the planning of treatment for upgrading the wastewater for use as a cooling tower water feed

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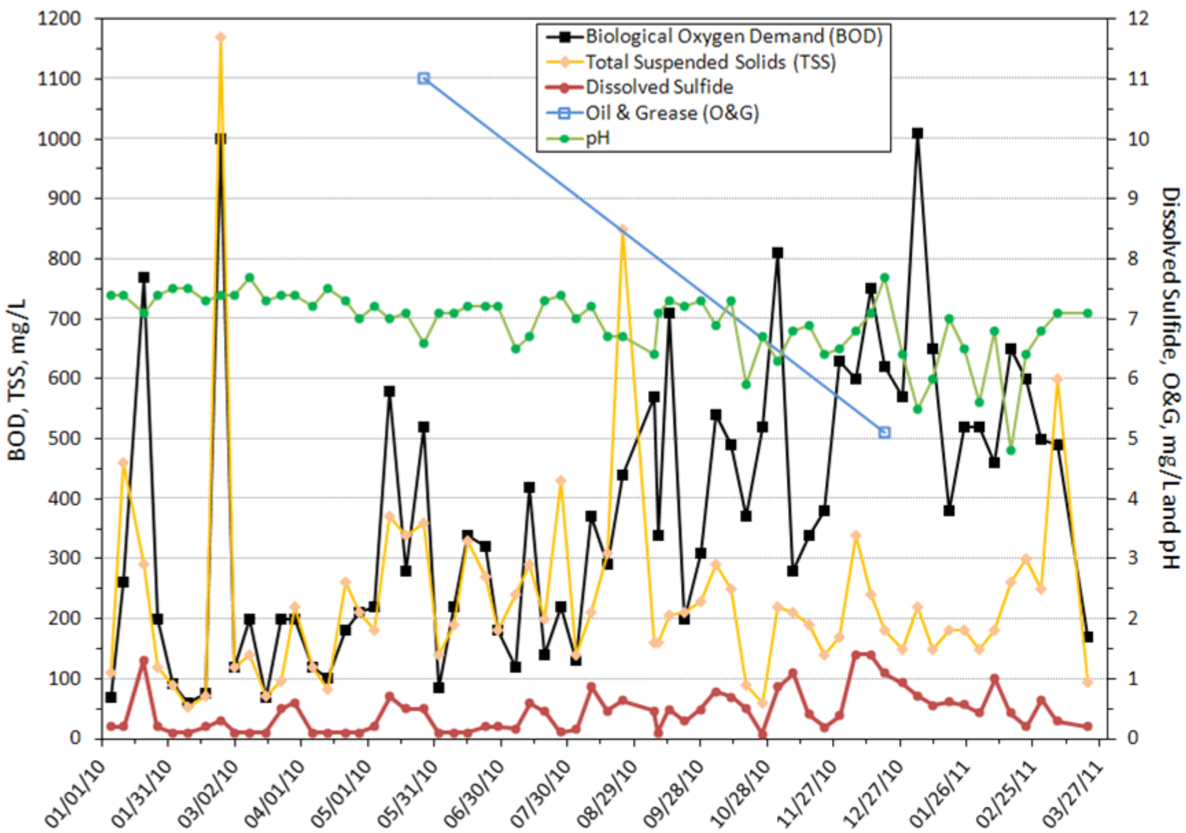
[4] Carawan, R.E. et al. 1979. Fruit and Vegetable Water and Wastewater Management. Extension Special Report No. AM-18E. January. Purdue University – Cornell University.

stream, it was recognized that there may be complimentary value in combining membrane technology with the existing biological processing to generate a high quality water feed stream for the cooling towers that would meet specifications for minimizing operational costs due to minerals that cause scale formation and soluble organics that promote biological growths. In general, aerobic biological treatment could be used to remove easily degradable organic molecules (such as sugars, starches, fats and volatile acids) that are usually small in size, leaving refractory organics that are slower to oxidize (such as polysaccharides, proteins, cellulose, hemicelluloses, lignin, pectin, etc.).

Figure 2: **Gills Onions WWTP Effluent Assay Results from Years 2010 and 2011**



Size exclusion based filtration, such as UF and nanofiltration could then be used to further treat the wastewater stream to remove most of the recalcitrant organic matter; the reject stream from these filtration steps could then be recycled back to the front of the biological process for further treatment with biooxidation. The water stream that could be treated with biological processing followed by rough filtration followed by UF and nanofiltration would conceivably undergo more than 95% reductions in soluble organics and suspended solids. It was also hypothesized that partial removal of large inorganic species such as sulfate, calcium and magnesium would also likely be achieved, thereby contributing to efforts to remove constituents that promote scale formation in cooling towers. An example of a set of specifications given by Evapco for the Gills Onions cooling tower is given in Table 2.

Table 2: Recirculating Water Chemistry Guidelines for the Gills Onions Evapco Cooling Towers

Property	Range
pH	6.5 to 8.3
Hardness as CaCO3 (ppm)	50 to 300
Alkalinity as CaCO3 (ppm)	50 to 300
Total Suspended Solids (ppm)	<25
Bacteria Count (cfu/ml)	<10,000
Conductivity (Micro-mhos/cm)	<2,400 micro-mhos
Chlorides as Cl (ppm)	<250
Chlorides as NaCl (ppm)	<410
Sulfates (ppm)	<250
Silica as SiO2(ppm)	<150

Source: http://www.evapco.com/sites/evapco.com/files/white_papers/113AA-Ops-Maint.pdf

Examination of the composition of Gills Onions effluent (Figure 2) from the existing aerobic treatment system shows that the only parameters of Table 1 that are not complied with are the total bacteria count and the total suspended solids; for this reason, a filtration train including rough filtering followed by MF/UF followed by nanofiltration was selected for testing to examine the quality of treated wastewater that could be achieved at each stage of processing.

The strategy contemplated for Gills Onions was not without precedent. Various types of membrane filters are used in many industrial processes to achieve useful separations of solutions containing microbes and soluble organic matter. Membrane filters are pressure driven processes that achieve separations of constituents through size exclusion. Types of membrane filters are usually classified by ranges of applicable pore sizes and molecular weights of constituents that are allowed to pass. Classes of membrane filters include MF, UF, NF, and RO, as shown in Figure 3.

In this diagram, RO is capable of removing bacteria and organics as well as simple salts. However, the removal of simple salts (such as sodium chloride) is not required to meet the specifications for a Gills Onions plant water reuse system. The RO process typically operates at high pressure drops (225-1,000 psi) and requires far higher energy inputs for operation compared to UF and MF that often operate at pressure drops of less than 100 psi and yet are able to achieve separations of microbes and many organic compounds. For this reason, UF and NF are employed in many industrial operations to achieve many useful separations at low energy inputs. Examples of membrane separations include those listed in Table 3 related to industries that include dairy, food and beverage, pharmaceuticals, and textiles. Capabilities and operating costs of the different types of membrane filters are shown in Table 4.

At the Gills Onions aerobic treatment plant, it is highly probable that efficient removals of microbes can be achieved through inexpensive UF. It is also likely a good fraction of the residual BOD can also be removed from the effluent through UF or NF. Much of the wastewater organic matter is oxidized and comprised of easy-to-degrade compounds that are simple in structure and of small molecular size. The simple organic compounds such as sugars and organic acids will degrade rapidly, leaving behind a residual of “refractory” compounds in the effluent that is likely to be dominated by slower-to-degrade, larger compounds such as proteins, polysaccharides, starches, cellulose and hemicellulose molecules, etc. If a low-cost process can be economically applied to the removal of bacteria and refractory organics from effluent of the activated sludge unit, this stream could be easily utilized to satisfy the substantial water demand of the Gills Onions cooling towers.

The criteria set for selecting the membrane filtration unit included the following:

- Applicability–proven experience of the selected membrane process with analogous separations performed in the food and beverage industries.
- Capability–potential to meet water polishing performance targets that comply with the specifications for cooling tower influent water as shown in Table 2.
- Cost–reasonable capital and energy expenses projected for the application.
- Integration–reduced footprint and easily integrated with the Gills Onions plant equipment.

These considerations provided the basis for the rationale of combining aerobic biological treatment followed by low-pressure-drop size exclusion membranes (down to MF/UF for NF sizing) to generate a water stream with low concentrations of bacteria, lower concentrations of soluble organics and scale forming minerals, to prevent fouling of the cooling tower.

Figure 3: Classification of Membrane Separation Processes

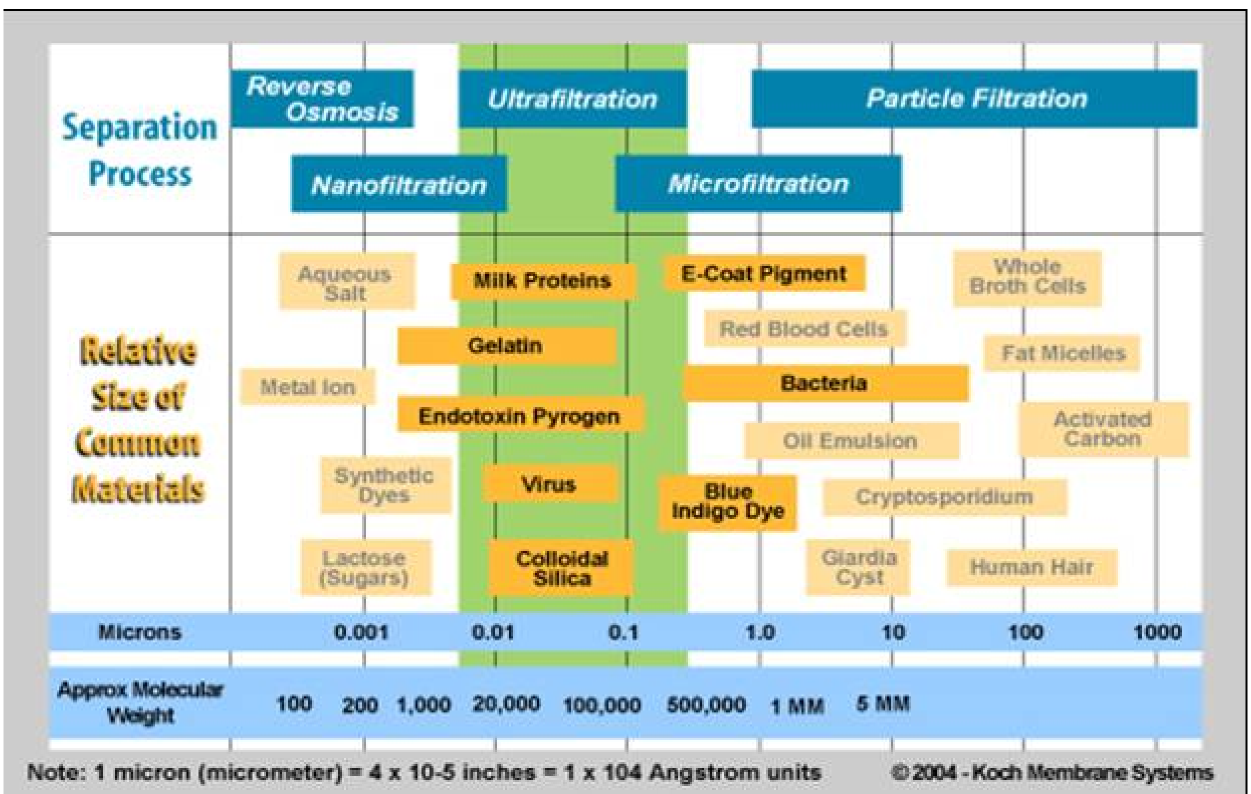


Table 3: Examples of Membrane Filtration Applications in Industry

Industry	Segment	Incoming Product	Permeate	Concentrate	Benefits
Dairy	Cheese	Salty Whey	Salty Wastewater	Desalted Concentrated Whey	Reduces transportation costs as well as recovery of lactose and whey
Food and Beverage	Baking	Single Strength Stream – Later Cook	Salt and Water Minerals	Gelatin	Desalt gelatin for better whipping properties
Pharma-ceutical	Drug	Raw Antibiotics	Salty Waste Product	Desalted, Concentrated Antibiotics	Increases value of product
Clothing	Textile	Slurry Mix	Dyes	Water, Salts, BOD, COD and Color	Desalting dyes for higher value product

Table 4: Capabilities and Operating Costs of Membrane Filters

Feature	Microfiltration	Ultrafiltration	Nanofiltration	Reverse osmosis
Polymers	Ceramics, Polypropylene, Polysulfone, Polyvinylidene fluoride, Polytetrafluoro-ethelyne, Polyacrylonitrile	Ceramics, Cellulosics, Polysulfone, Polyvinylidene fluoride	Thin film composites Cellulosics,	Thin film composites, Cellulosics, Polysulfonated, Polysulfone
Pore size range (microns)	0.1-1.0	0.001-0.01	0.0001-0.001	<0.0001
Molecular weight cutoff range (daltons)	>100,000	2,000-100,000	300-1,000	100-300
Operating pressure range (psi)	<30	20-100	50-300	225-1,000
Suspended solids removal	Yes	Yes	Yes	Yes
Dissolved organics removal	Yes	Yes	Yes	Yes
Dissolved inorganics removal	None	Yes	Yes	Yes
Microorganism removal	Protozoan cysts, algae, bacteria*	Protozoan cysts, algae, bacteria,* virus	All*	All*
Osmotic pressure effects	None	Slight	Moderate	High
Concentration capabilities	High	High	Moderate	Moderate
Permeate purity	High	High	Moderate-high	High
Energy usage	Low	Low	Low-moderate	Moderate
Membrane stability	High	High	Moderate	Moderate
Operating costs ($/1,000 gal)	0.50-1.00	0.50-1.00	0.75-1.50	1.50-5.00

* Under certain conditions, bacteria will grow through a membrane.
SOURCE: Cartwright Consulting Company, Minneapolis, Minnesota © 1999

2.2.1 Considerations for Biological–Membrane Process Integration

Early in the project, several directions were considered for the combining of aerobic biological treatment with the size exclusion physical separation capability of membrane treatment. As previously described, processing assets that existed at Gills Onions at the initiation of this effort included the treatment of the raw wastewater with dissolved air flotation and sedimentation followed by introduction into the extended aeration process. Given the existence of considerable amounts of treatment equipment, three options were considered for pilot and large scale testing at the Gills facility.

Option 1. Conversion of the Gills Onions aeration basin into MBR using a commercial equipment package.

Option 2. Use of an existing, efficient aeration basin to achieve bio-oxidation of soluble organics followed by a sequence of filtration consisting of rough filtering, UF and nanofiltration.

Option 3. Enhanced aerobic treatment consisting of the aeration basin followed by an aerobic SBR to provide added soluble organics removal followed by a sequence of filtration consisting of rough filtering, UF and NF.

Information on Option 1 was obtained from several commercial firms that offered the technology. Schematics of the GE ZeeWeed MBR package are shown in Figures 4 and 5. In principle, an UF membrane cassette system is immersed into the mixed liquor of an activated sludge suspension in order to achieve a permeate water stream that is reduced in suspended solids, leaving behind the bacteria that is returned to the aeration basin for more contacting with organics in the feed water. Not shown in the diagram is the certain degree of sludge wasting that is necessary to avoid overloading the system with sludge mass. One of the advantages of the MBR, however, is the ability to maintain a good range of microbial mass in the aeration chamber.

A strong advantage of the process is shown in the treatment of wastewater streams of low organic content (of less than 200 mg/L) where the maintenance of an acceptable concentration of active sludge in the aeration basin (at total suspended solids levels of at least 1,000 mg/L) may be challenging. Markets for the MBR technology seem to be aimed at publicly owned treatment works (POTWs) and industrial wastes treating wastewaters of soluble organics less than 300 mg/L of BOD_5.

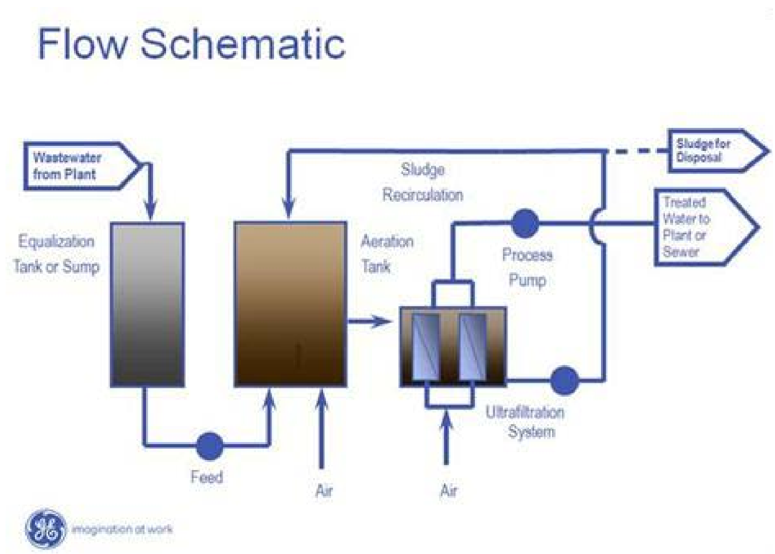
The Gills Onions facility raw wastewater, however, contains soluble organics in the range of 1,000- 2,000 mg/L and should not require the aid of the UF feature of the MBR process design to maintain microbial concentrations in the aeration basin. Furthermore, costs obtained (Option 1) from vendors of the MBR technology indicated this option would be cost prohibitive. For the Gills treatment plant flow of 180,000 GPD, the cost of the MBR retrofit package for the conversion of the Gills extended aeration basins would exceed $1 million in capital cost, about five times the cost of a multistage filtering system that could be added to the existing aeration basin system for water conditioning to deliver the required flow to the cooling tower. On the basis of excessive cost, Option 1 was not pursued in pilot testing.

Option 2 was ruled out based on an evaluation of the functionality of the existing aeration basin at Gills Onions as it was not effective in mitigating the highly fluctuating TSS and BOD concentrations in the effluent.

After ruling out Options 1 and 2 based on above reasons, Option 3, consisting of enhancing the extended aeration system's performance in the bio-oxidation of soluble organic compounds followed by staged filtration was considered to the extent that a tank was outfitted with air sparging equipment and was started up and operated according to a protocol that was recommended in the literature for successful SBR operation (see Appendix A for the recommended protocol). In startup, settled waste activated sludge from the Gills Onions extended aeration unit was transferred to the SBR prior to startup. Following the SBR operating protocol of the Appendix, the SBR was operated over a two month trial period. In its operation, effluent from the extended aeration basin was fed to the SBR and, following a period of settling of the batch contents, effluent was discharged to an effluent storage tank.

Figure 4: Placement of UF Membrane Cassettes into an Aerobic Biological Reactor

Figure 5: Schematic of Commercial MBR Integrated Processing Equipment (Option 1)



Samples from the storage tank, however, indicated significant levels of fine suspended particulates (thought to resemble silt) that were higher than levels recommended by membrane filter media vendors. At this point, it was decided to try further treatment with settling followed by treatment of the water with rough filtration and MF/UF. These steps were successful in clarifying the SBR water. At commercial scale, the fine silt can be easily controlled using a continuously cleaned, pressurized media filter that can efficiently remove particulates down to below 0.5 microns. This media filter could then be followed by UF/MF, NF or all of these processes if needed.

2.2.1 Considerations for the Option 3 Selected for Testing

In the testing of the staged filters on the Gills Onions Plant wastewater, the principal focus was placed on Option 3 The considered advantages of an integrated biological treatment followed by staged filtration separate from the biological process included the following:

- It is a low cost option. The extended aeration process that already exists and operates at the Gills Onions facility is capable of reducing soluble organics from 1,000-2,000 mg/L BOD_5 down to the low range of 100-400 mg/L, a reduction of 70-85%. For a small portion of the effluent that is to be reused as in this demonstration project, a small SBR could be constructed and operated to provide further biological treatment.
- Externally added to the biotreatment basins, the filtration processes and their components are easily accessed, inspected and maintained.
- Footprint requirements for staged filtration are very low, less than 10% of the area requirements for biological treatment.
- External filtration trains of Option 3 can be easily expanded with modest demands on space if added water is needed to satisfy future cooling tower water demands.

CHAPTER 3: Identify and Select Membrane Filtration Systems

The identification, selection and procurement of a membrane filtration system for operation prior to demonstration of the full-scale system is described in detail in the "Membrane Filter System Identification and Selection Report" as a deliverable for Task 2.

Based on the flow scheme selected for the membrane filtration system (i.e., Option 3, Chapter 2), which is shown in Figure 6, six vendors were identified as potential suppliers of a membrane unit for pilot operation: WSI International, Miller Leaman, X-Flow North America, Midwest Water Services, Advanced Hydro and KiVAR Chemical Technologies (formerly V2 Advanced Technologies). Although all these six vendors were well qualified, KiVAR Chemical Technologies (Bakersfield, CA) was chosen to configure and procure a pilot membrane filtration system for use in this project, shown in Figures 7-10. This choice was based on the recommendation made by Gills Onions due to their excellent prior working relationship, reputation and close proximity to Oxnard for facilitating both pilot- and full-scale demonstration of the membrane system for this project.

The prefiltration media and membranes selected for testing (Figure 6) are shown in Table 5 and the corresponding specification sheets are shown in Figures 11-17. Performance results of these membranes are discussed in Chapter 4, Pilot-Scale Membrane System.

Figure 6: Flow Scheme for the Membrane Filtration System

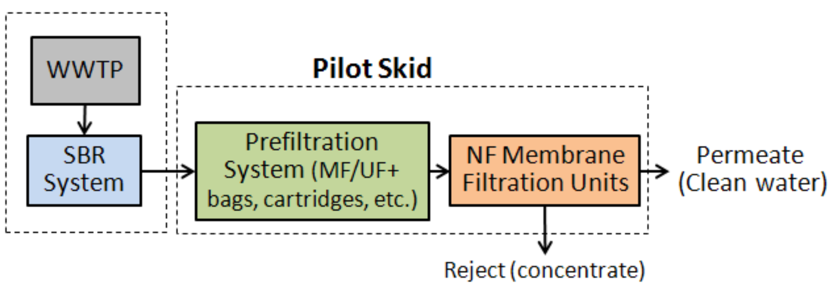


Figure 7: Pilot-Scale NF Membrane Filtration Units in Skid

Figure 8: Prefiltration System in Skid

(0.2-μm filters are shown in Figure 9)

Figure 9: WaterTEC 0.2-μm Membranes as Part of the Prefiltration System

(located downstream of filters shown in Figure 8)

Figure 10: Integrated Pilot Prefiltration and NF Membrane Filtration Systems

(upstream 0.2-μm filters not shown)

Table 5: Membranes Selected for Pilot System Testing

Manufacturer/Vendor	Model/Type	Rating	Drawing Tag #
Nanofiltration System			
DOW Filmtec	NF 90-4040	400-ft^2 active membrane area	4040 Membranes
DOW Filmtec	NF 270-4040	400-ft^2 active membrane area	4040 Membranes
Trisep	4040-XN80-TSF	85-ft^2 active membrane area	4040 Membranes
Trisep	4040-XN45-TSF	85-ft^2 active membrane area	4040 Membranes
Prefiltration System			
Filter Specialists Inc.	BPM0100X01	100 μm	F-310, F-320
Harmsco, Inc.	Dual density	10 μm-1 μm	F-350, F-360
Harmsco, Inc.	Dual density	10 μm-5 μm	F-330, F-340
Graver Technologies	WaterTEC-0.2-20PE (asymmetric)	0.2 μm	F1, F-380, F-390, F-400, F-410

Figure 11: Dow Filtec Membrane (NF90) Specification Sheet (Pg 1of 2)

Product Information

FILMTEC™ Membranes

FILMTEC NF90-400/34i Nanofiltration Element

Features

The DOW FILMTEC™ NF90-400/34i nanofiltration element is a high area and high productivity element offering an industry wide unique combination of features:

- High removal rate of salts, including nitrates and iron,
- High removal rate of organic compounds such as pesticides, herbicides, and THM precursors.
- A 34 mil feed spacer to lessen the impact of fouling on pressure drop across a vessel and to enhance cleaning effectiveness.

The DOW FILMTEC™ NF90-400/34i is listed to ANSI/NSF61.
For more information visit: http://www.nsf.org/Certified/PwsComponents

In addition, the DOW FILMTEC™ NF90-400/34i includes the typical DOW FILMTEC product features:

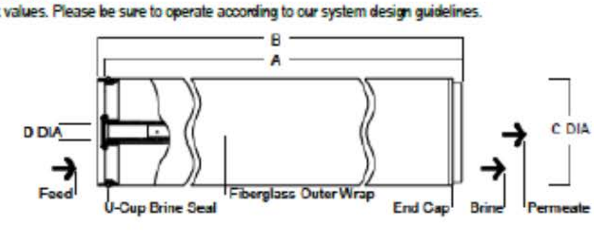
- iLEC™ interlocking end caps reduce system operating costs and the risk of o-ring leaks.
- The oxidative free membrane manufacturing process results in high membrane robustness and long term stable performance.
- The widest pH range for cleanings (pH1 to pH13) allows effective cleanings even in cases of severe fouling.
- The automated, precision fabrication gives a greater number of shorter membrane leaves thus reducing fouling while maximizing element efficiency.

Product Specifications

Product	Part number	Nominal Active Surface Area ft² (m²)	Product Water Flow Rate gpd (m³/d)	Stabilized salt rejection (%)
NF90-400/34i	11023067	400 (37)		
NaCl			7,500 (28.4)	85 – 95
$MgSO_4$			10,000 (37.9)	>97

1. Permeate flow and salt passage based on the following test conditions:
   2,000 mg/l NaCl, 70 psi (0.48 MPa), 77°F (25°C) and 15% recovery.
   2,000 mg/l MgSO4, 70 psi (0.48 MPa), 77°F (25°C) and 15% recovery.
2. Flow rates for individual elements may vary +/-15%.
3. The above specifications are benchmark values. Please be sure to operate according to our system design guidelines.

Figure 1



Product	Single-Element Recovery	Dimensions – inches (mm) A	B	C	D
NF90-400/34i	15%	40 (1,016)	40.5 (1,029)	7.9 (201)	1.125 ID (29)

1. Refer to FilmTec Design Guidelines for multiple-element applications and recommended element recovery rates for various feed sources. 1 inch = 25.4 mm
2. Element to fit nominal 8.00-inch (203 mm) I.D. pressure vessel.

Figure 12: Dow Filtec Membrane (NF90) Specification Sheet (Pg 2 of 2)

Operating Limits

Membrane Type	Polyamide Thin-Film Composite
Maximum Operating Temperature[a]	113°F (45°C)
Maximum Operating Pressure	600 psig (41 bar)
pH Range, Continuous Operation[a]	3 - 10
pH Range, Short-Term Cleaning (30 min.)[b]	1 - 13
Maximum Feed Flow	SDI 5
Free Chlorine Tolerance[c]	<0.1 ppm

a. Maximum temperature for continuous operation above pH 10 is 95°F (35°C).
b. Refer to Cleaning Guidelines in specification sheet 609-23010.
c. Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty, FilmTec recommends removing residual free chlorine by pretreatment prior to membrane exposure. Please refer to technical bulletin 609-22010 for more information.

Important Information

Proper start-up of reverse osmosis water treatment systems is essential to prepare the membranes for operating service and to prevent membrane damage due to overfeeding or hydraulic shock. Following the proper start-up sequence also helps ensure that system operating parameters conform to design specifications so that system water quality and productivity goals can be achieved.

Before initiating system start-up procedures, membrane pretreatment, loading of the membrane elements, instrument calibration and other system checks should be completed.

Please refer to the application information literature entitled "Start-Up Sequence" (Form No. 609-02077) for more information.

Operation Guidelines

Avoid any abrupt pressure or cross-flow variations on the spiral elements during start-up, shutdown, cleaning or other sequences to prevent possible membrane damage. During start-up, a gradual change from a standstill to operating state is recommended as follows:

- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.
- Permeate obtained from first hour of operation should be discarded.

General Information

- Keep elements moist at all times after initial wetting.
- If operating limits and guidelines given in this bulletin are not strictly followed, the limited warranty will be null and void.
- To prevent biological growth during prolonged system shutdowns, it is recommended that membrane elements be immersed in a preservative solution.
- The customer is fully responsible for the effects of incompatible chemicals and lubricants on elements.
- Maximum pressure drop across an entire pressure vessel (housing) is 50 psi (3.4 bar).
- Avoid permeate-side backpressure at all times.

Regualtory Note

These membranes may be subject to drinking water application restrictions in some countries: please check the application status before use and sale.

DOW FILMTEC™ Membranes
For more information about DOW FILMTEC membranes, call the Dow Water & Process Solutions business:

North America:	1-800-447-4369
Latin America:	(+55) 11-5188-9222
Europe:	800 3 694 6367
Italy:	800 783 825
South Africa:	0800 99 5078
Pacific:	+800 7776 7776
China:	+800 889 0789

www.dowwaterandprocess.com

Figure 13: Dow Filmtec Membrane (NF270) Specification Sheet (pg 1 of 2)

Product Information

DOW

DOW FILMTEC™ Membranes

DOW FILMTEC NF270-400 Nanofiltration Element

Features

The DOW FILMTEC™ NF270-400 element is a high area, high productivity element designed to remove a high percentage of TOC and THM precursors while having a medium to high salt passage; medium hardness passage.

The DOW FILMTEC NF270-400 element is an ideal element for surface and ground water applications where good organic removal is desired with partial softening in order to maintain a minimum level of hardness for organoleptic properties and preservation of distribution networks.

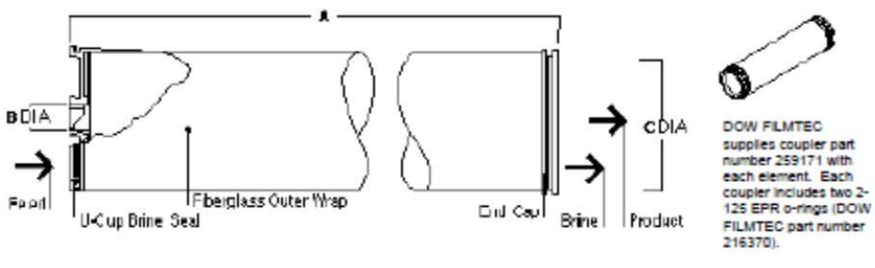
The high active area membrane combined with low net driving pressure of the membrane allows the removal of these compounds at low operating pressure.

Product Specifications

Product	GMID	Nominal Active Surface Area ft² (m²)	Product Water Flow Rate gpd (m³/d)	Stabilized Salt Rejection (%)
NF270-400	148822	400 (37)	12,500 (47.3)	97.0

1. Permeate flow and salt rejection based on the following test conditions: 2,000 mg/l $MgSO_4$, 70 psi (0.48 MPa), 77°F (25°C) and 15% recovery.
2. Flow rates for individual elements may vary +/-15%.
3. The above specifications are benchmark values. Please be sure to operate according to our system design guidelines.
4. The typical permeate flow for NF270-400 when tested on 500 mg/L $CaCl_2$, 70 psi (0.48 MPa), 77°F (25°C), and 15% recovery is 14,700 gpd with a stabilized salt rejection of 40-60%. These are not guaranteed values.

Figure 1



Product	Single-Element Recovery	A	B	C
			Dimensions – Inches (mm)	
NF270-400	15%	40 (1,016)	1.5 (38)	7.9 (201)

1. Refer to DOW FILMTEC Design Guidelines for multiple-element applications and recommended element recovery rates for various feed sources.
2. Element to fit nominal 8.00-inch (203 mm) I.D. pressure vessel.

Figure 14: Dow Filmtec Membrane (NF270) Specification Sheet (pg 2 of 2)

Operating Limits

• Membrane Type	Polyamide Thin-Film Composite
• Maximum Operating Temperature	113°F (45°C)
• Maximum Operating Pressure	600 psig (41 bar)
• Maximum Pressure Drop	15 psig (1.0 bar)
• pH Range, Continuous Operation[a]	3 - 10
• pH Range, Short-Term Cleaning (30 min.)[b]	1 - 12
• Maximum Feed Flow	70 gpm (15.9 m^3/hr)
• Maximum Feed Silt Density Index	SDI 5
• Free Chlorine Tolerance[c]	<0.1 ppm

[a] Maximum temperature for continuous operation above pH 10 is 95°F (35°C).
[b] Refer to Cleaning Guidelines in specification sheet 609-23010.
[c] Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty, DOW FILMTEC recommends removing residual free chlorine by pretreatment prior to membrane exposure. Please refer to technical bulletin 609-22010 for more information.

Important Information

Proper start-up of reverse osmosis water treatment systems is essential to prepare the membranes for operating service and to prevent membrane damage due to overfeeding or hydraulic shock. Following the proper start-up sequence also helps ensure that system operating parameters conform to design specifications so that system water quality and productivity goals can be achieved.

Before initiating system start-up procedures, membrane pretreatment, loading of the membrane elements, instrument calibration and other system checks should be completed.

Please refer to the application information literature entitled "Start-Up Sequence" (Form No. 609-02077) for more information.

Operation Guidelines

Avoid any abrupt pressure or cross-flow variations on the spiral elements during start-up, shutdown, cleaning or other sequences to prevent possible membrane damage. During start-up, a gradual change from a standstill to operating state is recommended as follows:

- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.
- Permeate obtained from first hour of operation should be discarded.

General Information

- Keep elements moist at all times after initial wetting.
- If operating limits and guidelines given in this bulletin are not strictly followed, the limited warranty will be null and void.
- To prevent biological growth during prolonged system shutdowns, it is recommended that membrane elements be immersed in a preservative solution.
- The customer is fully responsible for the effects of incompatible chemicals and lubricants on elements.
- Maximum pressure drop across an entire pressure vessel (housing) is 50 psi (3.4 bar).
- Avoid permeate-side backpressure at all times.

DOW FILMTEC™ Membranes
For more information about DOW FILMTEC membranes, call the Dow Water & Process Solutions business:

North America:	1-800-447-4369
Latin America:	+55 11-5188-9222
Europe:	+32 3-450-2240
Pacific:	+60 3 7965 5392
Japan:	+813 5460 2100
China:	+86 21 3851 4988

www.dowwaterandprocess.com

DOW®

Figure 15: Trisep NF Membrane (TS80) Specification Sheet

TRISEP CORPORATION

PRODUCT SPECIFICATION

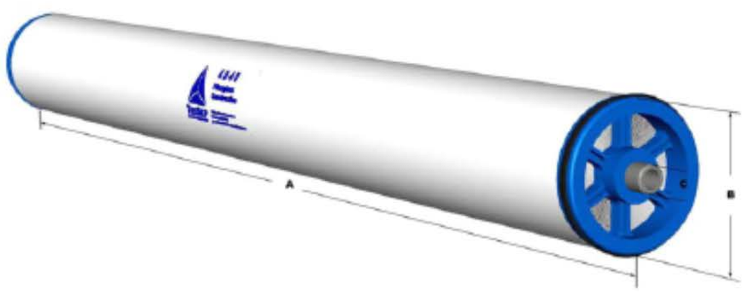
4" TS80 Nanofiltration Element Series

Model	Permeate flow GPD (m3/day)*	Average Salt Rejection (%)	Minimum Salt Rejection (%)
4040-TS80-TSF	2,000 (7.0)	99.00	97.00

Performance is based on the following test conditions: 2,000.0 ppm $MgSO_4$, 110.0 psi, 25°C, 15% recovery, pH 8.0, 30 minutes operation.

OPERATIONAL AND DESIGN DATA

Membrane Type	ANM Aromatic Polyamide Advanced Nanofiltration Membrane
Configuration	Spiral Wound, Fiberglass Outer Wrap
Active Membrane Area	85 ft² (7.9 m²)
Recommended Applied Pressure	40 - 200 psi (3 - 14 bar)
Maximum Applied Pressure	600 psi (41 bar)
Recommended Operating Temperature	35 - 113°F (2 - 45°C)
Feedwater pH Range	2 - 11 continuous
Chlorine Tolerance	<0.1 ppm
Maximum Feed Flow	20 GPM (4.5 m3/hr)
Minimum Brine Flow/Permeate Flow Ratio	5:1
Maximum SDI (15 minutes)	5.0
Maximum Turbidity	1 NTU



Element Weight: 15 (7)

Length (**A**): 40.0 (1,016) Diameter (**B**): 4.0 (101) Permeate Tube (**C**): 0.75 (19.1)

Units in pounds and inches, units in paranthesis in kilograms and millimetes.

Mechanical Configuration: Filmtec Style Core Tube

Feed Spacer: 0.031" thick diamond spacer

* Permeate flow is clean water flux at standard conditions above. Not applicable for all feedwater conditions. Individual element's permeate flow may vary +/- 15%.

Figure 16: Trisep NF Membrane (XN45) Specification Sheet

TRISEP CORPORATION

PRODUCT SPECIFICATION

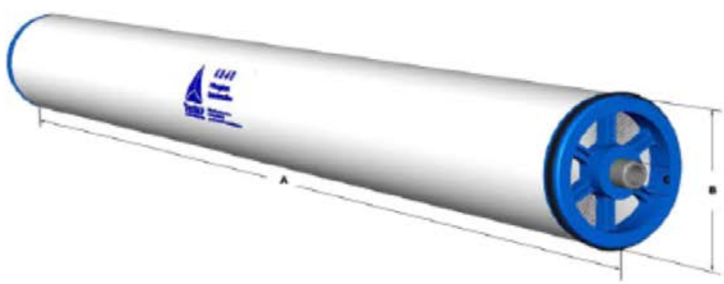
4" XN45 Nanofiltration Element Series

Model	Permeate flow GPD (m3/day)*	Average Salt Rejection (%)	Minimum Salt Rejection (%)
4040-XN45-TSF	2,000 (7.0)	95.00	92.00

Performance is based on the following test conditions: 2,000.0 ppm $MgSO_4$, 110.0 psi, 25°C, 15% recovery, pH 8.0, 30 minutes operation.

OPERATIONAL AND DESIGN DATA

Membrane Type	XN45 Polyamide Advanced Nanofiltration Membrane
Configuration	Spiral Wound, Fiberglass Outer Wrap
Active Membrane Area	85 ft² (7.9 m²)
Recommended Applied Pressure	40 - 200 psi (3 - 14 bar)
Maximum Applied Pressure	600 psi (41 bar)
Recommended Operating Temperature	35 - 113°F (2 - 45°C)
Feedwater pH Range	2 - 11 continuous
Chlorine Tolerance	0.5 ppm nominal, 1.0 ppm max
Maximum Feed Flow	20 GPM (4.5 m3/hr)
Minimum Brine Flow/Permeate Flow Ratio	5:1
Maximum SDI (15 minutes)	5.0
Maximum Turbidity	1 NTU



Element Weight: 15 (7)

Length (A): 40.0 (1,016) Diameter (B): 4.0 (101) Permeate Tube (C): 0.75 (19.1)

Units in pounds and inches, units in paranthesis in kilograms and millimetes.

Mechanical Configuration: Filmtec Style Core Tube

Feed Spacer: 0.031" thick diamond spacer

* Permeate flow is clean water flux at standard conditions above. Not applicable for all feedwater conditions. Individual element's permeate flow may vary +/- 15%.

Figure 17: WaterTec Membrane Filter Specification Sheet

WaterTEC™ Filter Series

Absolute Rated Polyethersulfone Membrane Filter Cartridges

The WaterTEC filter series is constructed of absolute rated, hydrophilic, asymmetric polyethersulfone membrane and polypropylene components. The filter is designed for overall filtration economy and provides excellent flow rates and throughputs.

Filter Features–Benefits

- Low pressure drop reduces energy costs
- High dirt holding capacity minimizes change-outs and down time
- All thermal bonded construction with no adhesives
- Available in all common configurations to allow use of existing filter housings
- Cost effective absolute filtration
- All materials are FDA listed for food and beverage contact (U.S. CFR, Title 21)
- Meets USP, Class VI for plastics

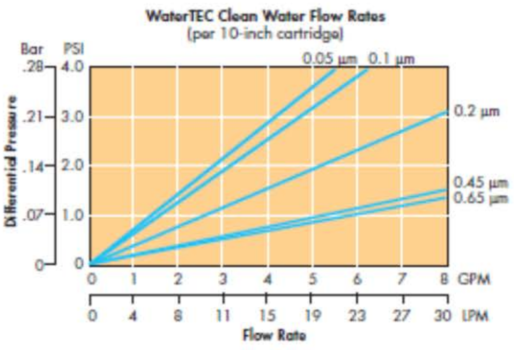
Filter Specifications

Media:	*Asymmetric polyethersulfone*
Inner core, end caps, cage:	*Polypropylene*
Support layers:	*Spunbonded Polypropylene*
Gaskets/O-Rings:	*Buna-N, EPDM, Silicone, Viton, Teflon Encapsulated Viton (O-Rings only)*
Micron ratings:	*0.05, 0.1, 0.2, 0.45, 0.65 µm*
Compatibility: Compatible with most common chemical cleaning, sanitizing and sterilizing agents and with pH range from 1–14. Consult factory for specific compatibility information	
Cleanliness:	*Non-fiber releasing, no wetting agents*
Dimensions and Operating Parameters	
Typical nominal lengths:	*9.75", 10", 20", 30", 40" (24.7, 25.4, 50.8, 76.2, 101.6cm)*
Outside diameter:	*2.7" (6.86 cm)*
Inside diameter:	*1.1" (2.79 cm)*
Surface area:	*6 ft². (0.56m²) per 10 inch element*
Maximum sustained operating temperature:	*180°F (82°C) at 20 psid (1.38 bar)*
Maximum differential pressure:	*60 psid @ 80°F (4.14bar @ 27°C) 30 psid @ 160°F (2.07 bar @ 71°C) 15 psid @ 200°F (1.03 bar @ 93.3°C)*
Recommended change-out pressure:	*35 psid (2.4 bar)*

Typical Applications

- General water filtration
- DI water prefilter
- DI water post filter
- Aqueous based chemical processing

WaterTEC FLOW RATE



CHAPTER 4:
Pilot-Scale Membrane System

4.1 Procure Membranes

Testing of the pilot-scale membrane system was conducted per the scheme (Option 3) discussed in Chapter 2. Appropriate membranes listed in Table 4 above were procured from KiVAR Chemical Technologies. A test setup was devised and fabricated as shown in Figure 18. The final layout of the SBR/membrane filtration system is shown pictorially in Figure 19. Overall, the scheme shown in Figures 18 and 19 utilizes water from the last stage of the existing WWT system in the plant wherein it is pumped into the 40,000-gallon SBR for aeration and settling (as per procedure in Appendix A) and then transferred into the 9,000-gallon holding tanks. The holding tank effluent is then pumped into the prefiltration assembly to pre-screen any residual solids before feeding to the NF membrane filtration system. An output of up to 2 GPM of permeate is obtained from this revised scheme for feeding the membrane system during pilot testing.

Figure 18: Pilot-Scale NF Membrane System Test Setup PFD

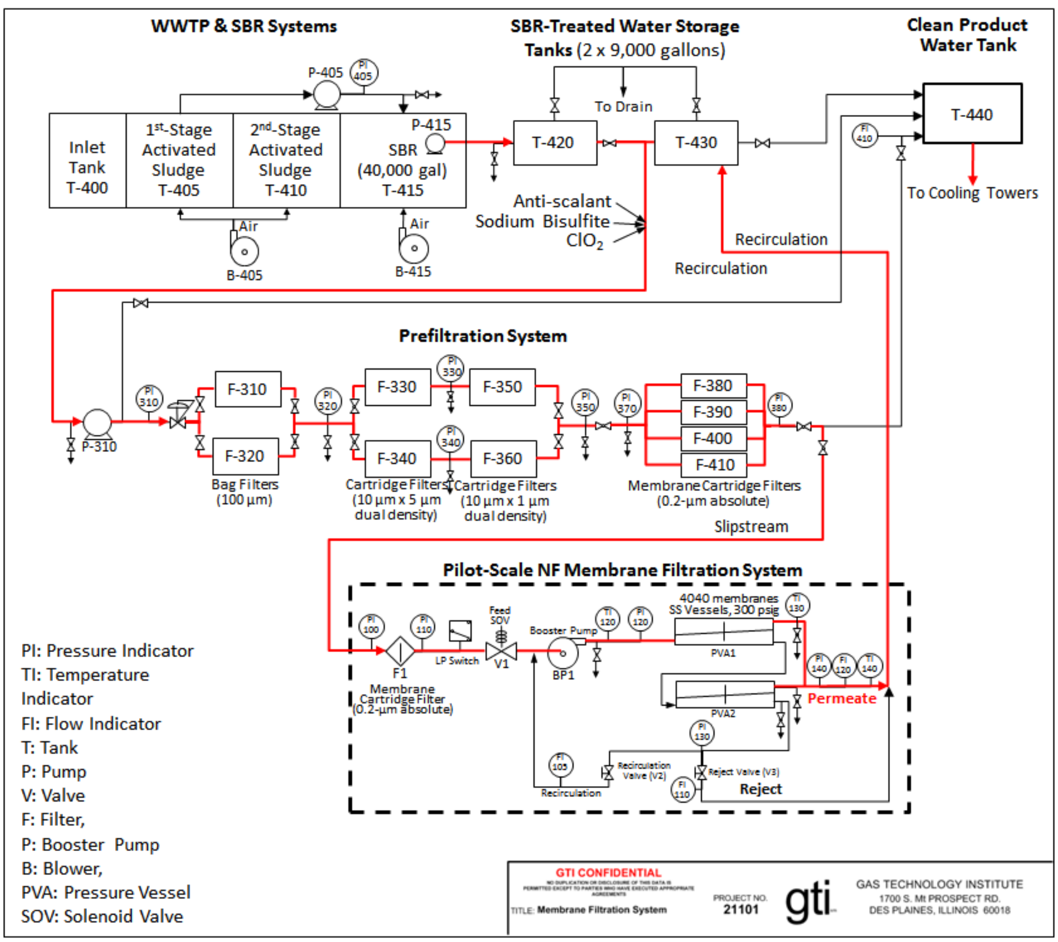
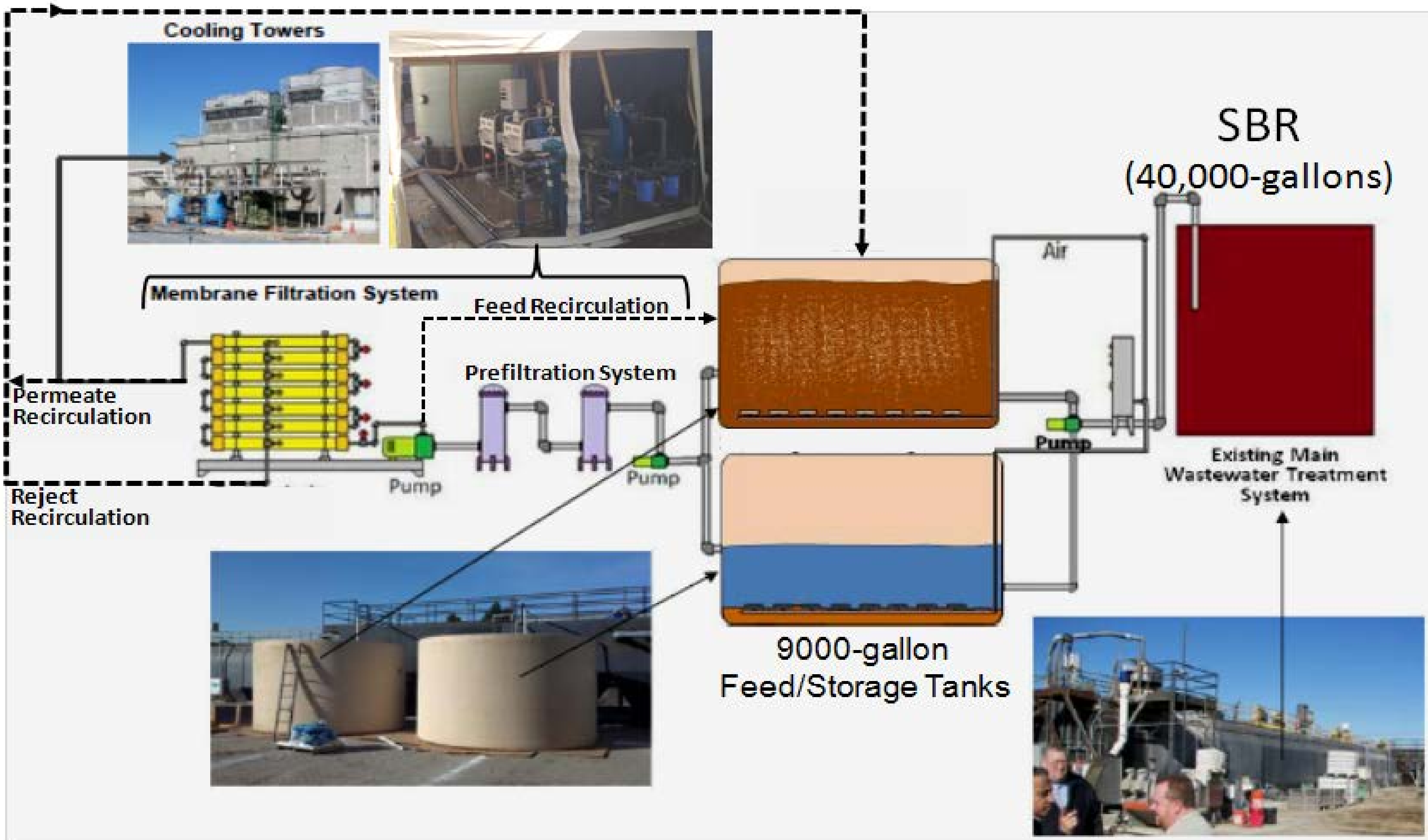


Figure 19: Layout of the SBR and Membrane Filtration Systems



4.2 Testing

Membrane filtration testing was conducted per the following procedure:

- Install membranes and complete electrical and piping hookups.
- Transfer treated water from the SBR system to the 9,000-gallon water storage tanks for feeding the filtration systems.
- Start test by circulating the feed water using the system pump through the prefiltration system (bypassing the NF membranes) and back to the storage tanks while changing out any filters as needed based on their pressure drops. The prefiltration system is designed to remove turbidity, particulates and reduce the feed water SDI, a measure of fouling potential. Low SDIs typically correlate with longer membrane operational time before cleaning is required.
- When the system reaches a point where the filters can run for eight hours without an increasing pressure drop start SDI testing of the prefiltration system outlet water.
- Continue recirculating feed water until SDI values are ≤5 (per membrane manufacturer specifications). In the current configuration, after about seven days of recirculation low SDI values consistently less than 1 were attained demonstrating the efficiency of the prefiltration system.
- Place NF membrane system back in line and measure pressure drops of the NF membranes and the prefiltration system as a function of time.
- Obtain and submit feed, permeate and reject water samples for analysis to determine water quality.

4.3 Test Results

4.3.1 Initial Membrane Screening Testing

Screening testing of the NF membranes in Table 4 was carried out to determine an initial baseline for the total hardness of the permeate water. To expedite the screening process, this testing was conducted without recirculation of the feed water (i.e., the SBR water in the storage tanks). However, for membrane life testing given below, the recirculation filtering of feed water was utilized (as discussed in Section 4.2).

For the Dow Filmtec NF90 and NF 270 membranes, the total hardness in the product water was determined to be <20 and 170 PPM, respectively. The product conductivities were measured to be 48 and 670 μmho, and total dissolved solids (TDS) 39 and 617 PPM, respectively, and followed the same increasing trend as total hardness. Although the total hardness level for the membrane product water to supply the Gills Onions evaporative condensers has not yet been established, a level of ~100 PPM has been tentatively suggested from a previous assessment of the cooling tower water chemistry. Based on the above data, it appears that the NF90 membranes are tighter and the NF270 membranes somewhat looser than desired.

In order to slightly reduce the hardness to the desired ~100 PPM level, Trisep TS80 membranes were installed (MWCO of 100-200 Daltons) in the pilot unit for evaluation to achieve the desired water hardness of ~100 PPM. A total hardness of 30 PPM was obtained, which is also lower than the desired quality for use in the evaporative condensers.

The Trisep 4040-XN45-TSF membranes, with a MWCO of 500, were tested last. The total hardness of the permeate produced was in the range of 230 PPM and although higher than the desired 100 PPM is still considered acceptable for use in the plant's evaporator condensers. The membrane had been operated for over 14 hours and had the longest life of all the membranes tested.

It also became evident during this initial membrane testing that additional prefiltration would be needed to remove the submicron particles present in water sourced from the 9,000-gallon holding tanks to obtain reliable, long-term operation of the pilot membrane filtration units at nominal design flow rates. As a result, the additional filtering using 0.2-µm membrane cartridge filters along with recirculation filtering as described above in section 4.2 was employed in the life test discussed below.

4.3.2 Membrane Life Testing

Based on the above positive results for the Trisep XN45 membrane, life testing commenced using this membrane. The filtration train–consisting of rough particle filters, MF (to 0.2-µm particle size), and NF in series–was started up on November 2, 2013 and accrued ~190 hours of continuous operation (Table 5). Pressure drops across the prefiltration (rough filter and MF) and NF units remained at reasonable values while generating permeate product water of more than 2 GPM; these data are shown in Table 6. The modest and steady pressure drops experienced of less than six psig across the nanofilters indicate no significant problems with fouling over the eight days of operation.

In the separations achieved with respect to organic compounds in the water, the parameters of total organic carbon (TOC) and biochemical oxygen demand (BOD) were highly useful to compare between streams and provided a good basis to determine performance. While TOC is a measure of the total carbon content of the soluble organic matter in a sample, the BOD is a result of a biological transformation where soluble oxygen from the water matrix is used to biologically convert soluble organic matter into carbon dioxide. Since the BOD test is conducted over a 5-day period, the organic matter that is oxidized to CO_2 is, by definition, the bioconvertible fraction of the total organic matter present. Thus, the BOD:TOC ratio can be used as a measure of the biodegradability of the soluble organics present in the wastewater. The higher the ratio, the higher the fraction of total organic carbon that will be degradable in aerobic environments of a bioprocess or receiving natural waters such as a river, stream, lake, ocean, etc. As a membrane process removes the larger organic molecules (such as cellulose, hemicellulose, pectin, etc.) that are more difficult to degrade and allows the smaller organics (such as sugars) to pass through (as the permeate), it would be expected that the permeate would exhibit a significantly higher BOD:TOC ratio than the influent or reject streams.

This was, in fact, what was observed from the pilot scale operation of the nanofiltration system operated on wastewater effluent obtained from the Gills Onion Plant extended aeration plant (Table 7); the BOD:TOC ratio in the permeate (SP4) was more than ten times the BOD:TOC ratio measured in the influent (SP3) and reject streams (SP5), strongly indicating that the mechanism of TOC reduction was through the size exclusion of the larger (and more refractory) organic compounds. Equally important, the nanofiltration unit was able to control TOC and BOD levels to very low organic levels (well below 10 mg/l for BOD and well below 5 mg/l for TOC) that are considered to be non-problematic for sustainable cooling tower operations.

Water quality data of the feed and outlet of the prefiltration system, and permeate and reject streams from the NF membranes are shown in Table 8.

Table 6: Pressure Drop and Flow Data Collected from the Pilot Filtration Unit

		NF Membrane System					Prefiltration System		
Date/TOD	Run Time, hrs	Inlet, psig	Outlet, psig	Pressure Drop, psi	Permeate Flow, gpm	Reject Flow, gpm	Inlet, psig	Outlet, psig	Pressure Drop, psi
11/2/13 2:00 PM	0	100.0	94.2	5.8		2.01	0.0	0.0	0.0
11/3/13 8:00 AM	5.5								
11/5/13 4:00 AM	49.5	100.0	94.2	5.8	2.11	2.01	0.0	0.0	0.0
11/7/13 12:47 PM	106.3	100.0	94.2	5.8					
11/8/13 12:47 PM	130.3	100.0	94.2	5.8					
11/10/13 7:00 PM	184.5	100.0	94.2	5.8					

Table 7: BOD and TOC Results of Pilot-Scale Testing with TriSep NX45 NF Membranes

Sample Port	Sample Date		
	11/4/2013	11/5/2013	11/6/2013
	BOD, PPM		
SP1	4.5	2.8	1.2
SP2	4.5	3.2	2.1
SP3	4.6	3.5	3.0
SP4	4.8	4.0	4.0
SP5	7.6	7.0	5.3
	TOC, PPM		
SP1	11	13	13
SP2	12	12	13
SP3	11	12	13
SP4	1.2	1.0	1.3
SP5	21	24	25
	BOD/TOC Ratio		
SP1	0.41	0.22	0.09
SP2	0.38	0.27	0.16
SP3	0.42	0.29	0.23
SP4	4.00	4.0	3.1
SP5	0.36	0.29	0.21

Sample Port (SP) Location

SP1: SBR tank outlet

SP2: Prefiltration system inlet

SP3: Post 0.2-μm filters

SP4: NF membrane permeate

SP5: NF membrane reject/concentrate

Table 8: Water Quality Results of Pilot-Scale Testing with TriSep NX45 NF Membranes

	Conductivity, μMHO	Total Dissolved Solids, mg/L	Total Hardness, PPM	M Alkalinity, PPM	P Alkalinity, PPM	pH	Chloride, PPM
11/2/2013							
Prefiltration inlet	1813	1436	450	130	0	6.70	160
Post 0.2-μm filters	1802	1428	450	130	0	6.70	160
NF permeate	1120	864	170	120	0	6.61	160
NF reject	2437	2013	710	160	0	6.61	160
11/3/2013							
Prefiltration inlet	1818	1432	450	130	0	6.70	160
Post 0.2-μm filters	1810	1432	450	130	0	6.69	160
NF permeate	1118	840	170	120	0	6.62	160
NF reject	2437	2016	700	170	0	6.61	160
11/4/2013							
Prefiltration inlet	1821	1433	450	130	0	6.78	150
Post 0.2-μm filters	1821	1435	450	130	0	6.78	150
NF permeate	1107	819	160	120	0	6.70	150
NF reject	2452	2021	700	170	0	6.72	150
11/5/2013							
Prefiltration inlet	1820	1439	450	130	0	6.92	150
Post 0.2-μm filters	1819	1446	450	130	0	6.92	150
NF permeate	1102	781	140	120	0	6.88	150
NF reject	2461	2047	690	180	0	6.82	150
11/62013							
Prefiltration inlet	1823	1434	440	130	0	7.09	150
Post 0.2-μm filters	1820	1437	440	130	0	7.09	150
NF permeate	1004	774	130	130	0	7.01	150
NF reject	2482	2059	680	180	0	7.02	150
11/7/2013							
Prefiltration inlet	1822	1441	440	130	0	7.28	150
Post 0.2-μm filters	1822	1444	440	130	0	7.27	150
NF permeate	991	762	130	130	0	7.10	150
NF reject	2499	2058	680	190	0	7.11	150
11/8/2013							
Prefiltration inlet	1832	1448	430	130	0	7.30	150
Post 0.2-μm filters	1826	1453	430	130	0	7.31	150
NF permeate	973	748	120	140	0	7.13	150
NF reject	2511	2063	650	190	0	7.18	150

CHAPTER 5:
Full-Scale Membrane System

5.1 Scaleup and Procurement

Gills Onions identified a previously used 50 GPM/72,000 GPD capacity membrane filtration unit (Figure 20) located in Arleda, CA, to accommodate full-scale demonstration in this project. The unit consists of membrane housings to accommodate full-size NF membranes, multistage feed water pump, pressure gauges, valves, conductivity meters, water sampling taps, and power hookup. In view of this the GTI-Gills Onions team visited the vendor site (enroute to Gills Onions for a project review meeting) to inspect the full-scale unit and found it suitable for use with minor modifications. This unit was subsequently purchased by Gills Onions (as part of their cost share obligation) and brought to the plant site for commissioning, shakedown and full-scale membrane demonstration testing.

Trisep XN45 NF membranes were selected for full-scale demonstration testing based on the favorable results obtained in the pilot-scale testing (~190-hours continuous operation) with these membranes. As a result, three 8-inch x 40-inch membranes were procured and installed in the unit. The manufacturer specification sheet for this membrane is shown in Figure21. A PFD of the test setup including the membrane unit and prefiltration systems is shown in Figure 22.

5.2 Demonstration Testing

All utility connections and shakedown of the unit were completed. Over 300 hours of testing were then conducted in three periods from 2/20/14-3/10/14. Water samples of the feed, permeate and reject (concentrate) streams were obtained and analyzed by a local water laboratory. Also, flow rates of the above three streams and TMP drop were measured. The test conditions and results are presented in the Tables 9-11 and discussed in detail below.

During the first test period from 2/20-2/22 membrane inlet pressure was initially regulated to a "low pressure" setting of 100 PSI with average 16 GPM (23,040 GPD) permeate flow, 98 GPM concentrate flow (6.2:1 ratio) and a 40 psi TMP across the three membranes. Acceptable permeate total hardness levels of 68 PPM were obtained. This configuration was maintained until 20:15 on February 22, at which time the system was voluntarily shut down to change the #2 bag filter out due to high pressure drop. Also at his time the generator powering the system and electrical components in the main panel of the NF unit failed. Testing was suspended for five days while the generator and damaged components were replaced. Total run time accrued was 59.25 hours at these initial flow and pressure settings.

The second test period began on 2/28/14 and continued for 111 hours at 100 PSI with similar results compared to period one: 17 GPM (24,480 GPD) permeate flow, 95 GPM concentrate flow (5.6:1 ratio), permeate total hardness levels of ~50 PPM and steady TMP of 40 PSI.

In the third test period (3/5-3/10) the inlet pressure was increased to 180 PSI inlet to determine its effect on the membrane system flow characteristics. This change resulted in a slight increase in the permeate flow rate to 19 GPM (27,360 GPD) and a slight decrease of the concentrate flow to 90 GPM (lower ratio of 4.7:1). A similar 40-psi TMP was observed but lower permeate total hardness levels of ~35 PPM were obtained. These conditions were maintained throughout the third period of testing of the ultrafiltration/nanomembrane system at full scale.

Figure 20: Two Views of Used 72,000-GPD Membrane Filtration Unit Equipped with Membranes in Place at Gills Onions Site

(40,000-gallon SBR tank shown in background in lower photo)

Figure 21: Trisep 8-inch NF Membrane (XN45) Specification Sheet for Full-Scale Testing

Model	Permeate flow GPD (m3/day)*	Average Salt Rejection (%)	Minimum Salt Rejection (%)
8040-XN45-TSA	9,500 (35.0)	95.00	92.00

Performance is based on the following test conditions: 2,000.0 ppm $MgSO_4$, 110.0 psi, 25°C, 15% recovery, pH 8.0, 30 minutes operation.

OPERATIONAL AND DESIGN DATA

Membrane Type..	XN45 Polyamide Advanced Nanofiltration Membrane
Configuration...	Spiral Wound, Fiberglass Outer Wrap
Active Membrane Area................................	365 ft² (33.5 m²)
Recommended Applied Pressure..................	40 - 200 psi (3 - 14 bar)
Maximum Applied Pressure..........................	600 psi (41 bar)
Recommended Operating Temperature........	35 - 113°F (2 - 45°C)
Feedwater pH Range....................................	2 - 11 continuous
Chlorine Tolerance.......................................	0.5 ppm nominal, 1.0 ppm max
Maximum Feed Flow......................................	80 GPM (18 m3/hr)
Minimum Brine Flow/Permeate Flow Ratio....	5:1
Maximum SDI (15 minutes)	5.0
Maximum Turbidity..	2 NTU

Element Weight: 45 (20)

Length (**A**): 40.0 (1,016) Diameter (**B**): 7.9 (200) Permeate Tube (**C**): 1.50 (38.1)

Units in pounds and inches, units in paranthesis in kilograms and millimetes.

Mechanical Configuration: TriSep Style Core Tube

Feed Spacer: 0.031" thick diamond spacer

* Permeate flow is clean water flux at standard conditions above. Not applicable for all feedwater conditions. Individual element's permeate flow may vary +/- 15%.

Figure 22: Full-Scale NF Membrane System Test Setup PFD

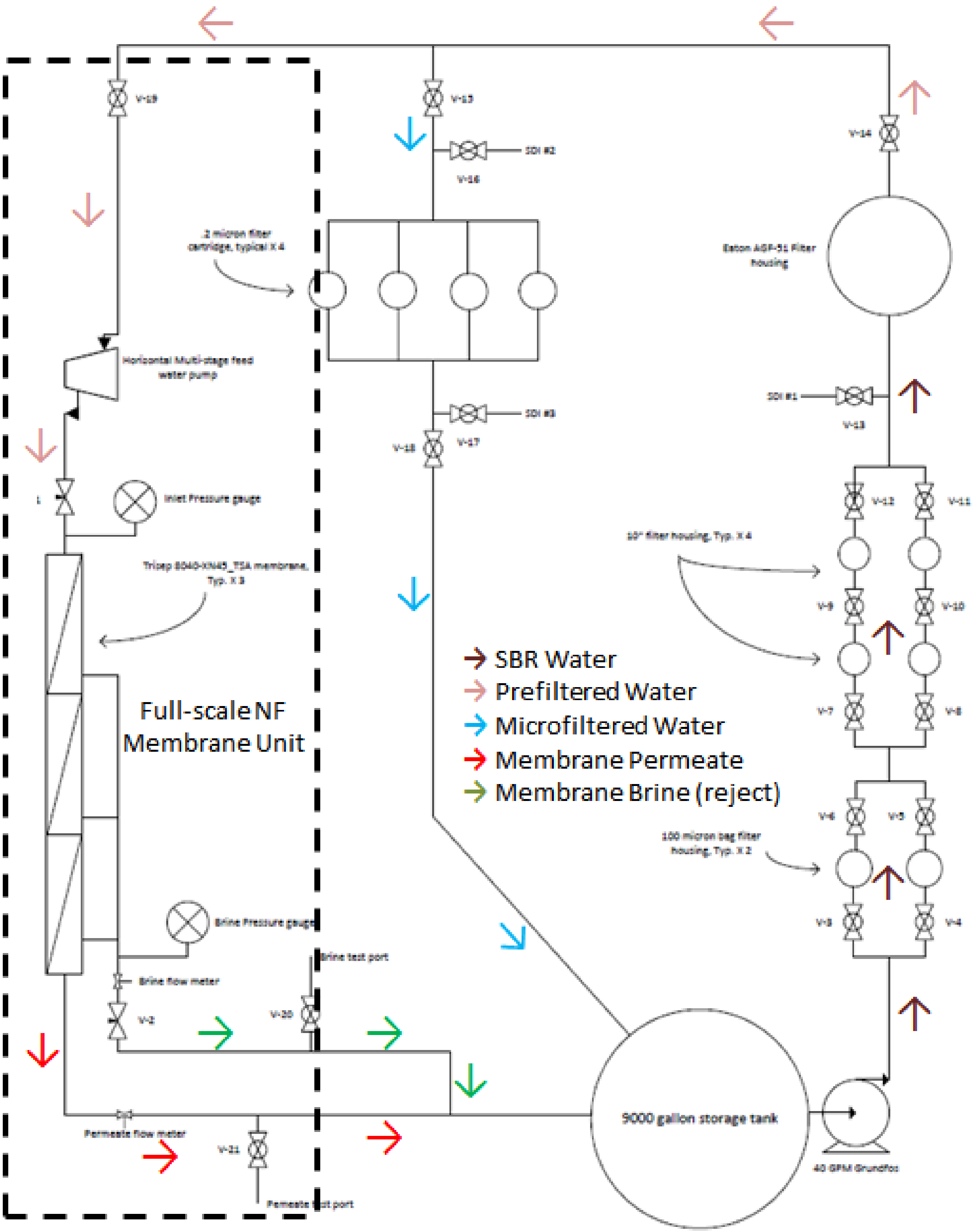


Table 9: Full-Scale NF Membrane System Test Conditions

Period #	1	2	3
Run Time, hr	59.25	111	132
Average Values			
NF Inlet Pressure, psig	100	100	180
Permeate Flow Rate, GPM	16	17	19
Concentrate Flow Rate, GPM	98	95	90
Pressure Drop Across NF Membranes, psi	40	40	40
Concentrate to Permeate Ratio	6.1	5.6	4.7
Total Concentrate Generated, gallon	348,390	632,700	712,800
Total Permeate Generated, gallon	56,880	113,220	150,480
Estimated Power Usage per Gallon Permeate, kWh	0.018	0.017	0.015

Table 10: Full-Scale NF Membrane System Test Results

Period #	1			2					3						Average		
Run Time, hr	2	30	55	4	29	58	83	106	5	35	58	83	107	124	Period #1	Period #2	Period #3
SBR Treated Storage Tank																	
Conductivity, µmho	3529	3548	3564	3588	3581	3589	3580	3583	3583	3584	3583	3580	3585	3583	3547	3584	3583
Total Dissolved Solids, mg/L	2589	2577	2589	2589	2578	2573	2577	2577	2578	2578	2578	2582	2578	2578	2585	2579	2579
Total Hardness, ppm	440	440	440	440	440	440	440	440	440	440	440	440	440	440	440	440	440
M Alkalinity, ppm	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
P Alkalinity, ppm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pH	6.77	6.77	6.77	6.77	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.77	6.79	6.79
Turbidity, NTU	0.9	0.9	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8	0.6	0.6
Post Prefiltration																	
Conductivity, µmho	3516	3529	3562	3566	3569	3563	3560	3562	3562	3562	3562	3563	3562	3561	3536	3564	3562
Total Dissolved Solids, mg/L	2576	2572	2576	2576	2570	2571	2579	2576	2576	2576	2576	2576	2576	2579	2575	2574	2577
Total Hardness, ppm	440	440	440	440	440	440	440	440	440	440	440	440	440	440	440	440	440
M Alkalinity, ppm	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
P Alkalinity, ppm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pH	6.75	6.75	6.75	6.75	6.77	6.77	6.77	6.77	6.77	6.77	6.77	6.77	6.77	6.77	6.75	6.77	6.77
Turbidity, NTU	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.667	0.6	0.6
NF Membrane Concentrate																	
Conductivity, µmho	4758	4867	4919	4919	4946	4946	4946	4946	4758	4762	4755	4761	4758	4759	4848	4941	4759
Total Dissolved Solids, mg/L	4122	4122	4177	4203	4210	4213	4198	4198	4111	4114	4119	4113	4112	4117	4140	4204	4114
Total Hardness, ppm	570	580	590	600	600	600	590	600	680	690	680	680	680	680	580	598	682
M Alkalinity, ppm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
P Alkalinity, ppm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pH	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79
Turbidity, NTU	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
NF Membrane Permeate																	
Conductivity, µmho	2538	2543	2539	2533	2531	2534	2523	2519	2136	2137	2134	2130	2136	2132	2540	2528	2134
Total Dissolved Solids, mg/L	1767	1759	1765	1760	1751	1758	1754	1762	1693	1693	1692	1698	1696	1698	1764	1757	1695
Total Hardness, ppm	68	68	68	52	51	50	50	51	36	36	35	36	36	36	68	51	36
M Alkalinity, ppm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
P Alkalinity, ppm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pH	6.71	6.71	6.71	6.71	6.7	6.71	6.71	6.71	6.71	6.71	6.71	6.71	6.71	6.71	6.71	6.71	6.71
Turbidity, NTU	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Table 11: BOD-COD Test Results for Full-Scale NF Membrane System

Sample #	1	2
Period #	3	3
Run Time, hr	33.2	56.8
	COD, mg/L	
Permeate	0	0
Concentrate	94	0
	BOD, mg/L	
Permeate	6.8	3.8
Concentrate	13	7.4
	TOC, mg/L	
Permeate	3.7	3.9
Concentrate	13	13
	BOD/TOC	
Permeate	1.84	0.97
Concentrate	1.00	0.57

5.3 Results

During all three periods of testing, flows and pressure readings were recorded and multiple water samples were taken of the water stream passing through each stage of membrane process treatment. Results of the flows and pressures measured through the membrane filter system, as shown in Table 8, indicate that permeate flows of 16 to 19 gpm were maintained at modest pressure drops across the nanomembrane of 40 psi.

Separations performance achieved with the membrane system are reflected in the data tabulated in Tables 9 and 10. Inorganic chemistry determinations that were performed (i.e. conductivity, total dissolved solids, total hardness, alkalinity, pH and turbidity) are tabulated in Table 9 for each sampling location along the treatment train and the total organic carbon (TOC), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) determinations at sampling locations around the nanofiltration process are shown in Table 10.

Data from these three tables indicate that multiple types of useful separations were efficiently achieved at a low pressure drop that is characteristic of nanofiltration processing. The most significant aspects of the results are summarized below:

- Treatment of the effluent of the aerobic biological reactor with ultrafiltration followed by nanofiltration showed that a substantial removal of organics was achieved with the nanomembrane, reducing the total organic carbon (TOC) by more than 67 percent. This represents a further polishing of the effluent of the biological treatment unit and provides a good control on residual carbon to levels acceptable for reuse as a cooling tower feedwater (TOC < 10 mg/l).
- The ratio of BOD to TOC increased significantly (by a factor of 1.8) as the treated wastewater stream passed from the influent to the permeate side of the nanofilter. This observation would infer that the larger, more refractory organic molecules are rejected by the membrane. In an integrated process flowsheet, the reject stream from the

nanofilter can be recycled to the influent end of the aerobic reactor for further biological breakdown of the slower-to-degrade refractory organics.

- Significant demineralization of wastewater was achieved with the nanofiltration step, causing the salinity to be decreased from nearly 3600 μmho to an average of about 2500 μmho or less, thereby enabling the effluent water stream to practically meet the specifications for cooling tower salinities.
- Substantial reductions in hardness of nearly 90% were achieved, causing harness to decline from around 440 down to about 50 mg/l as $CaCO_3$; most of this decline of hardness was due to the removal of calcium and magnesium ions. This process performance enabled the wastewater stream to become compliant with the hardness criteria for the cooling tower.
- No significant fouling of the nanofiltration membranes was observed; a low and stable pressure drop of about 40 psi or less was maintained across the entire operational periods for both pilot and full scale nanomembrane demonstration systems.
- TOC and BOD removals were enhanced. Effluent of the conventional extended aeration unit (biological process) located at the Gills Onion Facility was upgraded to a higher quality water stream by using follow-on treatment with membranes to achieve multiple water quality objectives to meet reuse specifications. Post-processing consisting of ultrafiltration followed by nanofiltration showed that a substantial additional removal of organics could be achieved to levels of TOC that were more than 67 lower than the effluent TOC.
- The above multipurpose treatment capabilities were achieved by the nanomembrane treatment train at energy costs that are less than $0.25/1000 gallons.

CHAPTER 6: Conclusions

The low cost improvement of existing wastewater treatment facilities using advanced filtration is a strategy that can lead to increased water reuse and reduced demands of freshwater among many types of industrial operations throughout California. The application of nanofiltration to enable the generation of water suitable for cooling tower use is an important example of the continued effort of the California Energy Commission to encourage and promote innovation in water management that leads to greater water conservation by industry in the coming decades which will contribute to the sustainability of the California economy. On the basis of the results of this project, the following conclusions can be made:

- In the management of wastewater effluents, Aerobic biological treatment alone is unable to condition the effluent to a quality consistently suited to meet manufacturer's specifications for water feeds for satisfactory operation of cooling towers. The high calcium content as well as elevated organic residuals in the effluent of aerobic biological processes represent a barrier to water reuse. However, the addition of removing fine suspended solids with ultra or microfiltration followed by nanofiltration has the potential of converting conventional biological treatment effluents to water streams that are able to meet feed water specifications for the reliable operation of cooling tower systems.
- Nanofiltration as an add-on process provides multiple treatment benefits in polishing the effluent of conventional biological treatment to achieve very low TOC levels as well as a significant demineralization of the water stream and efficient reductions of hardness that are important steps that are required for generating suitable cooling tower feed water.
- TOC and BOD removals were enhanced. Effluent of the conventional extended aeration unit (biological process) located at the Gills Onion Facility was upgraded to a higher quality water stream by using follow-on treatment with membranes to achieve multiple water quality objectives to meet reuse specifications. Post-processing consisting of ultrafiltration followed by nanofiltration showed that a substantial additional removal of organics could be achieved to levels of TOC that were more than 67 lower than the effluent TOC.
- The ratio of BOD to TOC increased significantly (by a factor of 1.8 to 10) as the treated wastewater stream passed from the influent to the permeate side of the nanofilter. This observation would infer that the larger, more refractory organic molecules are rejected by the membrane. In an integrated process flowsheet, the reject stream from the nanofilter can be recycled to the influent end of the aerobic reactor for further biological breakdown of the slower-to-degrade refractory organics.

- The Significant demineralization of wastewater was achieved with the nanofiltration step, causing the salinity to be decreased from nearly 3,600 μmho to an average of about 2,500 μmho or less, thereby enabling the effluent water stream to practically meet the specifications for cooling tower salinities.
- Substantial reductions in hardness of nearly 90% were achieved, causing harness to decline from around 440 down to about 50 mg/l as $CaCO_3$; most of this decline of hardness was due to the removal of calcium and magnesium ions. This process performance enabled the wastewater stream to become compliant with the hardness criteria for the cooling tower.
- No significant fouling of the nanofiltration membranes was observed; a low and stable pressure drop of about 40 psi or less was maintained across the entire operational periods for both pilot and full scale nanomembrane demonstration systems.

CHAPTER 7: Potential Benefits

The California Energy Commission has estimated that within California 19% of electricity use, 30% of non-power plant related natural gas and 86-million gallons of diesel fuel are consumed annually for water related uses.[5] Within the region where Gills Onions in Oxnard is situated, much of the incremental water demands are going to be addressed through the Southern Delivery System which transports water at an energy expenditure of about 4.63 MWh per acre ft (14.2 kWh/1000 gallons) of water delivered.

On the other hand, the application of NF to industrial water streams requires approximately 2 kWh/1000 gallons.[6] Preliminary filtration tests on the Gills Onions effluent water have resulted in pressure drop and water flux data consistent with the literature value of 2 kWh/1000 gallon energy requirement. If MF/UF is sufficient for satisfactory cooling tower operation, pressure drop requirements would be reduced by more than half and the energy requirement would fall to less than 1 kWh/1000 gallons. If total energy requirements for upgrading the Gills Onions water for reuse in the cooling tower reached a total of 3 kWh/1000 gallons, an energy savings of nearly 80% would be realized when compared to the incremental energy costs of transporting water to the Oxnard region using the Southern Delivery System (SDS).

[5] Natural Resources Defense Council. 2012. "Pipe Dreams: Water Supply Pipeline Projects in the West". Report available for download at www.nrdc.org

[6] Drewes, J. (CSM). 2009. An Integrated Framework for Treatment and Management of Produced Water. RPSEA Report No. 07122-12.

GLOSSARY

Term	Definition
BOD	Biochemical oxygen demand
BTU	British thermal unit
COD	Chemical oxygen demand
ft	Foot/feet
F	Fahrenheit
GPD	Gallons-per-day
GPM	Gallons-per-minute
GTI	Gas Technology Institute
kWh	Kilowatt hour
LDL	Lower detection limits
MBR	Membrane bioreactor
MF	Microfiltration
mg/L	Milligram-per-liter
MWCO	Molecular weight cut-off
MWh	Megawatt hour
NF	Nanofiltration
PFD	Process flow diagram
PPM	Parts-per-million
psi	Pounds-per-square inch
RO	Reverse osmosis
SBR	Sequencing batch reactor
SDI	Silt Density Index
TMP	Tansmembrane pressure
UF	Ultrafiltration
WWTP	Wastewater treatment plant

μm	Micron

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APPENDIX A:
Recommended Operational Modes of the Gills Onions Sequencing Batch Reactors (SBRs)

Overall Description of the Aerobic Treatment System

Objective: To generate at least 7,000 gallons of treated wastewater daily that is sufficiently low in biochemical oxygen demand (BOD) to be a suitable feed water for the particle and NF membrane separation units for the generation of water for cooling tower use.

Description of the System

Wastewater from the Gills Onions plant operations will be treated in their existing extended aeration basin.In order to ensure a sufficiently low effluent BOD concentration, two supplemental aerobic SBR units will be fed with the effluent of the extended aeration unit on a daily basis according to the protocol defined in the table below. Each day, the two SBR's will be operated in parallel and will together provide at least 7,000 gallons of treated water. SBR effluent will be discharged into a polished effluent tank that will serve as the feed to the membrane skid.

Startup Recommendations

Use a combination of the sludge from the extended aeration unit (existing on site) and a drum (50 gallons) of waste activated sludge from the local activated sludge treatment plant. This provides good inoculation from two working sources of aerobic treatment. Sludge volume in its settled state will occupy approximately 25-35 percent of the liquid volume of each SBR. Inoculation is a startup event. Once the SBRs are operating, sufficient bacterial mass will be generated from the oxidation of organics in the wastewater to create a buildup of microbial cells and excess sludge that will need to be wasted every day or several times a week. Supplemental sludge should not be added to the SBRs beyond the startup phase.

SBR Operation Description

Stage	Purpose	Duration	Comments
Fill	Add substrate (feed).	6 hrs: 11 am to 5 pm	Settled effluent from the extended aeration treatment system is fed to each ABR.Aeration system needs to deliver sufficient oxygen to maintain a dissolved oxygen level of over 3 mg/L O_2. During feeding, the aerators should be turned on. Contents of SBR are increased from 25% of max liquid level to 100%.

React	Reaction time Organics in the wastewater are oxidized by microorganisms.	14 hrs: 5 pm to 7 am	This step can be carried out over the night shift. During this stage, the aerators should be turned on. Aeration system needs to deliver sufficient oxygen to maintain a dissolved oxygen level of over 3 mg/L. No change in liquid level: 100% of max. liquid level.
Settle	Clarifying.Sludge is settled.	2 hrs: 7 am to 9 am	Aeration is turned off. No agitation. Quiescent settling is promoted. No change in liquid level: 100% of max liquid level.
Draw	Treated water (top layer) is removed from the SBR.	1 hr: 9 am to 10 am	Water level is reduced from 100 percent of max liquid level to 35 percent.Sample of this water should be taken to determine BOD and TOC levels.
Idle	Remove excess sludge.	1 hr: 10 am to 11 am	Water level is reduced from 35% of maximum liquid level to 25%.