ENHANCED COAGULATION AND UF TECHNOLOGY RESOLVE COMPLIANCE ISSUES FOR SWEETWATER, TEXAS

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Source Waters & Properties
Oak Creek Reservoir, Lake Trammel, Lake Sweetwater

Provisions of the IESWTR Require:

- ***Combined filter turbidity ≤0.3NTU in 95% of monthly measurements***
- ***3-log removal / inactivation of Giardia***
- ***4-log removal / inactivation of viruses***
- ***TOC removal under Stage 1 Disinfectants & Disinfection By-Products Rule***

Variable Quality

Turbidity Extremes
(<5 NTU to >100 NTU)

High in Organic Content

Parameter	Unit	Value
Turbidity	NTU	2-100
Alkalinity (as $CaCo_3$)	mg/L	136-195
pH	SU	7.5-8.2
TOC	mg/L	4.3-7.7
Chlorides	mg/L	117-164
Manganese (Total)	mg/L	0.004-0.04
Iron (Total)	mg/L	0.02-0.80
TDS	mg/L	700-1,000

Problem Statement

Plant placed into operation in 1925 with subsequent expansions and upgrades resulting in three (3) process trains

Conventional Surface Water Treatment
(rapid mix – flocculation – sedimentation – filtration)

Inability to meet a 25% reduction in total organic carbon (TOC) required under provisions of the Interim Enhanced Surface Water Treatment Rules

Could not meet the finished water turbidity requirements effective January 1, 2002

Plant shut-down December 31, 2001

Pilot Study

October, 1999 through March, 2000

Pilot Test Objectives for Membrane Technology

Organic Removal Performance

Turbidity / Particle Removal Capabilities

Overall Treatment Capability for Feed Water
from 3 Surface Water Sources

Design & Operation Parameters for a Full-Scale
8.0 MGD (expandable to 10.0 MGD)
Surface Water Treatment Plant

ZeeWeed® Immersed Membrane System

ZENON Environmental Systems, Inc.

Outside-in, hollow fiber UF modules directly immersed in the feed water

0.04-micron nominal and 0.10-micron absolute pore size

Membranes operate under a partial vacuum

Feed water conveyed to process tanks via pumps or by gravity

Water to be treated passes through the membrane, enters the hollow fibers and is pumped to storage

Air is introduced intermittently or continuously at the bottom of the membrane fibers, maintaining floc particle suspension in enhanced coagulation plants and allowing the membrane treatment system to operate at a high flux

Pilot Test Phasing & Objectives

Phase I	Optimize TOC Removal
Phase II	Optimize Membrane Design Parameters
Phase III	Low Recovery at Optimized Coagulant Dosage
Phase IV	High Recovery at Optimized Coagulant Dosage
Phase V	No Coagulant

Phase I – Optimize TOC Removal

Aluminum Sulfate (alum)

Traditionally used in the conventional process by the City of Sweetwater

Aluminum Chlorohydrate (ACH)

ZENON recommended for the enhanced coagulation process

Both chemicals were used for the pilot studies

Phase I – Optimize TOC Removal Results Summary

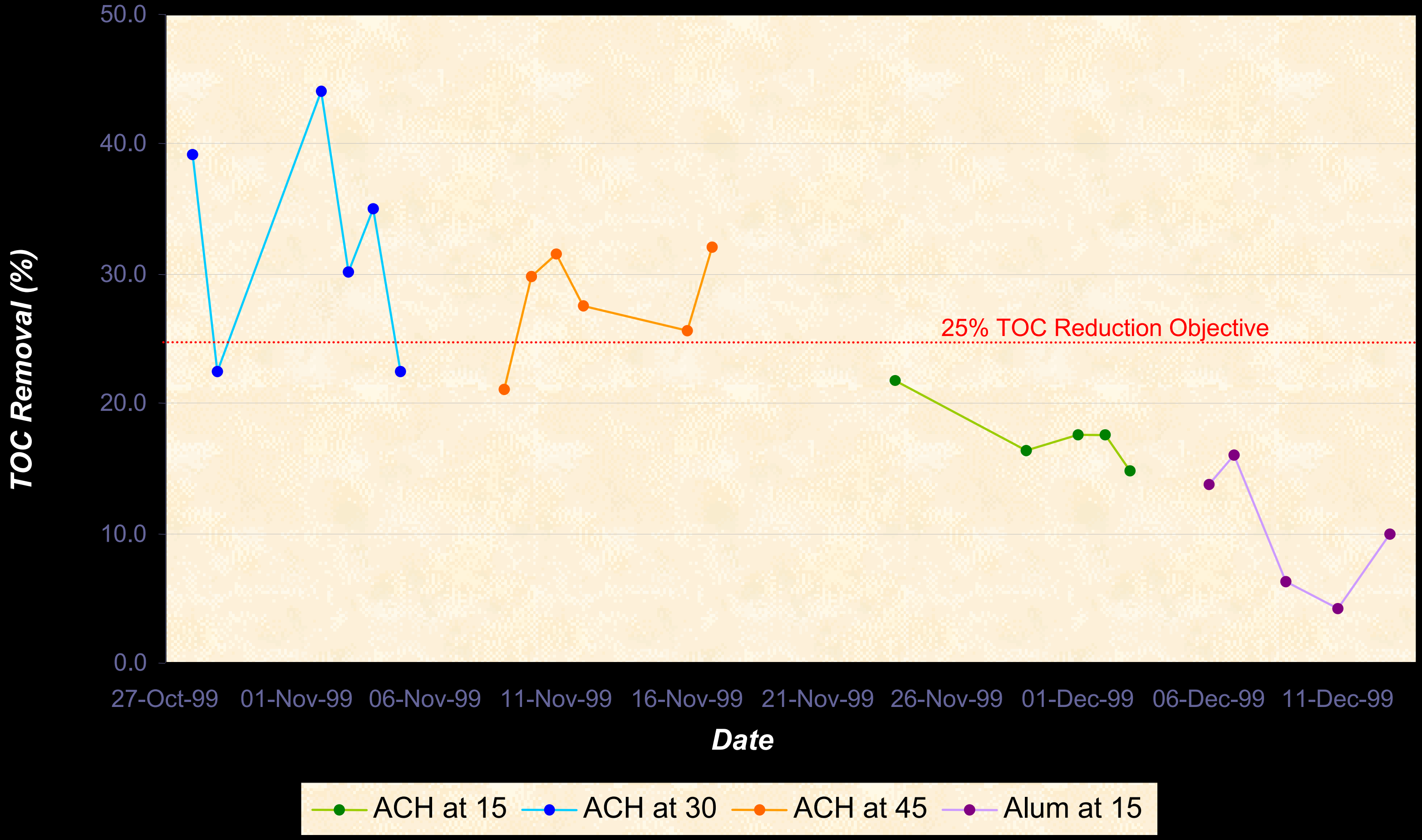
Maximum, Minimum and Average TOC values in the raw and permeate streams and the % reduction obtained with each chemical dosage.

Summary of TOC Removal Optimization

Parameter	Unit	ACH at 15ppm			ACH at 30ppm			ACH at 45ppm			Alum at 15ppm		
		max	*min*	*avg*	*max*	*min*	*avg*	*max*	*min*	*avg*	*max*	*min*	*avg*
Feed	mg/L	5.5	4.6	5.0	7.7	4.9	5.9	5.7	3.7	5.0	5.1	4.8	4.9
Permeate	mg/L	4.6	4.0	4.2	4.5	3.3	4.0	4.1	3.5	3.7	4.6	4.2	4.4
Removal	%	21.8	8.7	15.0	44.2	22.4	32.3	32.1	2.7	24.3	16.0	4.0	10.0

Note: Because of the high alkalinity of the raw water (average 150 mg/L), the pH was not altered, and thus the TOC reduction might not have been optimized with alum.

Phase I – Optimize TOC Removal Results



Operation Mode:

- Enhanced Coagulation
- Varying dosages of alum or ACH
- Constant Flux 35 gallons/ft2/day (gfd) & 90% recovery

Optimizing membrane performance during piloting is critical. The full-scale facility must meet design production rates, while avoiding the expense of excess membranes from a design that is "too conservative."

Phase II – Optimize Membrane Design Parameters

Flux

Permeability

Transmembrane Pressure

Backpulse Flux & Pressure

Backpulse Frequency / Duration

Phase II – Optimize Membrane Design Parameters

Flux

A measure of the rate at which the permeate passes through the membrane per unit of outside surface area of the membrane and reported in gallons/ft2/day (gfd).

Ideally, the pilot system is maintained at a constant flux with the transmembrane pressure (TMP) being the parameter that changes.

Net Flux

Calculation of flux taking into account the frequency and duration period of backpulsing, as well as lost production time.

Instantaneous Flux

Actual flux through the membrane; does not account for the backpulsing period resulting in a higher value.

The net operating flux (October 19 to January 24) was 35 gfd, which corresponds to an instantaneous flux of 36.5 gfd.

Variations occurred mainly during the latter phases of the study, when low recovery and high recovery were being tested.

Phase II – Optimize Membrane Design Parameters

Permeability

A measure of flux normalized against transmembrane pressure, typically reported in units of gfd/psi.

Typically temperature corrected to permit the influence of fouling to be determined.

Feed temperatures: 48° to 81°F (9° to 27 °C)

Permeate temperature: 73°F (23°C) constant (indicating a problem with the temperature gauge)

Initial temperature corrected permeability: 22 gfd/psi

During October 19, 1999, to January 24, 2000, the permeability slowly declined over time, averaging 0.2 gfd/psi each day before the first full tank soak clean. After the clean, the permeability declined more rapidly over the first week, then stabilized around 5 gfd/psi. Permeability range 5 to 15 gfd/psi during the entire pilot study.

Phase II – Optimize Membrane Design Parameters

Transmembrane Pressure

ZeeWeed® Membrane Systems typically operate at a low suction vacuum between (–1) and (–8) psi.

During normal production periods, the TMP slowly increases as the membrane becomes fouled.

Chemical cleaning is required as the vacuum approaches (–8) psi.

Transmembrane Pressure (TMP) increases and decreases due to several factors, including fouling and temperature changes.

Viscosity of water will increase as temperature decreases, requiring more force to process water through the membrane at lower temperatures.

At a constant flux, TMP will increase when the temperature decreases.

Phase II – Optimize Membrane Design Parameters

Backpulse Flux & Pressure

As a general rule, for the most effective backpulse, it is recommended to have the backpulse flux at 1.5 times the instantaneous permeate flux without exceeding a backpulse pressure of 8 psi.

Varied between 60 and 70 gfd for the majority of the pilot study.

Instantaneous Permeate Flux averaged 36 gfd.

Backpulse Pressure during each phase averaged between 4.5 and 6 psi.

Phase II – Optimize Membrane Design Parameters

Backpulse Frequency / Duration

Membrane backpulse was conducted on a 15-minute frequency for 15 seconds.

Chlorine residual of 3 to 5 mg/L was maintained in the CIP (clean in place) tank by means of a sodium hypochlorite puck.

No substantial differences in the before and after backpulse pressure measurements, indicating that the membrane was not greatly impacted by the solids concentration in the tank.

Phase III – Low Recovery at Optimized Coagulant Dosage

Summary of TOC Removal During Low Recovery				
Parameter	Units	ACH at 40 ppm		
		max	*min*	*avg*
Feed	mg/L	7.5	4.3	5.5
Permeate	mg/L	5.8*	3.5	5.1
Removal	%	28.0	18.3	24.3

**A higher permeate TOC level of 8.4 mg/L was recorded during this phase. However, study participants agreed that erroneous laboratory procedures account for this level.*

Included in the pilot study to investigate the effects of plug flow, since full-scale ZENON UF membrane process tanks are operated in a plug flow mode. The plug flow operation results in a significant reduction in the average solids concentration to which the membranes are exposed.

<u>January 26 to February 25, 2000 Operational Parameters</u>

- Optimized Coagulant Dosage at 40 mg/L ACH
- Recovery at Approximately 50%

TOC removal objective of 25% was met 67% of the time, with the average TOC reduction just under the 25% objective.

Phase IV – High Recovery at Optimized Coagulant Dosage

98% recovery operation conducted
February 25 and February 26, 2000

High Recovery Operation Samples

Feed Water – 6.2 mg/L

Permeate – 4.6 mg/L

TOC Removal = 25.8%

Phase V – No Coagulant

Full-scale operation at Sweetwater will require pretreatment as organic removal objectives cannot be met without chemical addition *and* operation of the system in an enhanced coagulation mode.

Results of operation without chemical addition:

Duration – March 1, 2000

Reduction - <10% in TOC

(5.4 mg/L feed water TOC; 4.9 mg/L permeate TOC)

All Phases – Turbidity / Particulate Removal

Texas Commission on Environmental Quality (TCEQ) is in the process of developing regulatory standards for membrane filtration. Currently they allow two methods for monitoring permeate quality.

Particle counting

> **Data collected during initial, full-scale operation is used to develop a statistical count for compliance.**

Turbidity

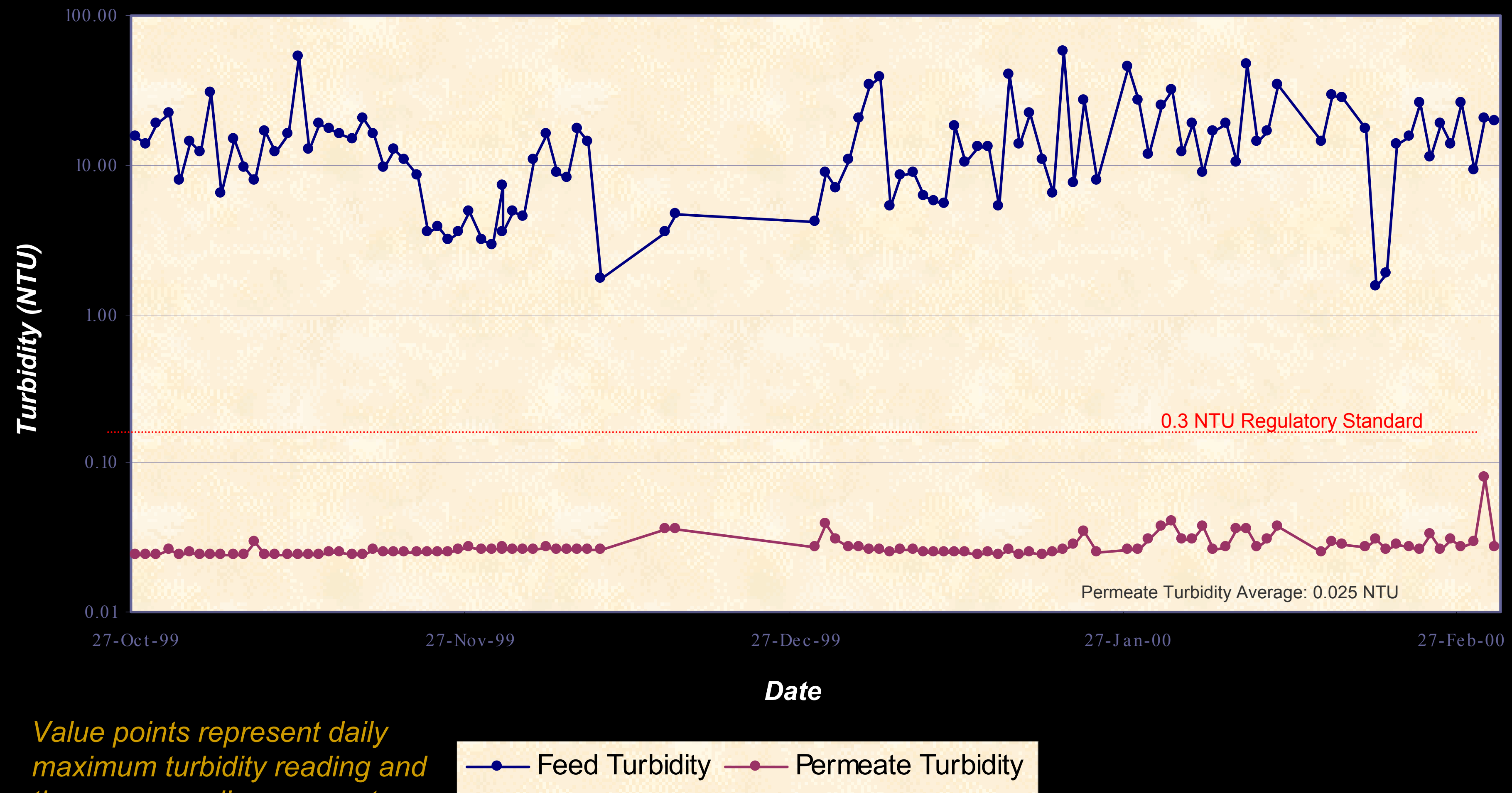
> **Regulations are clearly established with turbidity not to exceed 0.3 NTU.**

Permeate Quality

Typically measured and evaluated using particle counts.

Due to the established regulations, Sweetwater chose to measure turbidity in addition to particle counting.

All Phases – Turbidity / Particulate Removal



Value points represent daily maximum turbidity reading and the corresponding permeate turbidity value from the entire data set (utilizing online turbidimeters).

Goals were met in all phases.

Pilot Study Conclusions

Pilot Study Conclusions

Zee Weed® Immersed UF Membrane System achieved excellent permeate turbidity.

Avg. Turbidity-Feed: 10 NTU

Avg. Turbidity-Permeate: 0.025 NTU

<0.1 NTU 99% of the time and

≤0.2 NTU 100% of the time

Pilot Study Conclusions

A coagulant dosage between 30 and 40 ppm of ACH is recommended for the full-scale facility

Summary of TOC Reduction in the Permeate			
		Phases I & II ACH at 30 mg/L	Phases III & IV ACH at 40 mg/L
Removal	%	32.3	24.3

Bubble Tests conducted during start-up and decommissioning confirmed membrane integrity to the desired applied pressure of 5 psi

Particle counts in the permeate were <3 counts/mL 80% of the time, and <10 counts/mL 100% of the time

Membrane Integrity Test confirmed the integrity of the membrane for both pressure decay and particle counts

Pilot Study Conclusions

The pilot study was able to verify the design assumptions recommended by ZENON for the full-scale system including flux, recovery, backpulse frequency/duration, chemical cleaning protocol/interval, and membrane integrity monitoring. The overall membrane design recommendations from the pilot study are summarized as follows:

Design Net Flux: 36 gfd
Recovery: 90-95%
Air Flow Rate: 15 cfm
Backpulse Regime: 15 seconds every 15 minutes
Cleaning Interval: 4-6 weeks
Cleaning Protocol: Backpulse clean with citric acid at a concentration of 1,000 mg/L and sodium hypochlorite concentration of 500 mg/L

Full Scale Design Considerations

Design Elements of the Vacuum-Driven Membrane System

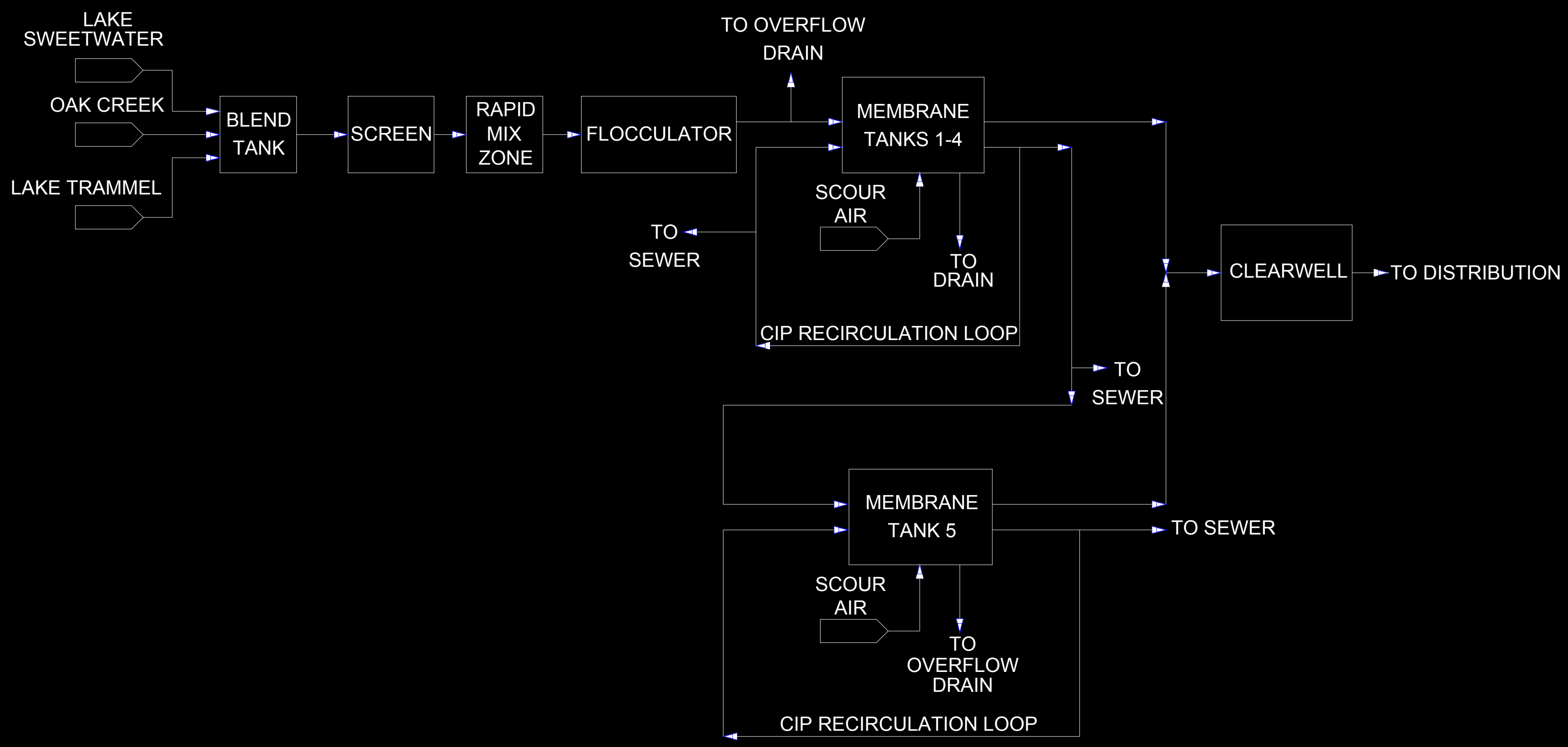
These design characteristics are key elements of the first immersed, vacuum-driven membrane system in Texas.

Rapid Mixing the Coagulant

Limited Flocculation Stage of 12.5 Minutes
Prior to Entering the Membrane Tanks

Secondary UF Process Tank to
Achieve 99% Recovery of Feed Water

Process Flow Diagram



Pretreatment

Objective

Chemical addition to optimize the coagulation process.

UF Membrane Protection

Additional screening step via an inclined, mechanically self-cleaned filter screen with 0.3mm screen openings.

Raw Water "Blend Tank"

Receives all three surface water sources. Designed with a cascade feature to uniformly blend waters and to reduce iron and manganese due to air stripping.

For plants with a design capacity of ≥3.0 MGD, State of Texas Rules & Regulations for Public Water Systems require:

- ***Two flocculation process trains, designed to operate in parallel.***
- ***Minimum theoretical detention time of 20 minutes when operated at design capacity.***
- ***A decrease in mixing intensity for multiple-stage flocculators as water passes from one stage to the next stage.***

Flocculation

Conventional Flocculation Objective:

Develop large/heavy floc particles to facilitate settling.

Enhanced Coagulation with UF Membrane Technology Flocculation Objective:

Generate a high concentration of pin-sized floc particles.

Flocculation-Reasons for the generation of a high concentration of pin-sized floc particles

Increase available surface area for adsorption of organic and colloidal particles, increasing particle removal efficiency.

Improved membrane performance due to more floc surface area and time available for adsorption, eliminating their availability as a foulant.

Need to form micro-floc particles of 0.1 microns and larger for effective separation of coagulated organic and colloidal particles.

Flocculation – Process Design

The Sweetwater flocculation process design includes two parallel trains of multi-stage, turbine mixers.

At the design flow rate of 8 MGD (30.28 MLD), a theoretical detention time of 12.5 minutes will be provided with a tapered mixing intensity of 100 sec^{-1} in Stage 1 down to 80 sec^{-1} in Stage 2.

Short-circuiting in flocculation basins is common, and can reduce actual detention times to less than one-half of the theoretical detention times. To minimize the impact of short-circuiting, the Sweetwater design includes a ported baffle wall between flocculator stages.

Membrane Process Units

ZENON Immersed UF membranes are designed in four (4) primary process tanks

At full-scale, they will operate at 90% recovery of feed water with flocculated solids in the process tanks averaging 210 mg/L
(when feeding 40 mg/L ACH with a raw water turbidity of 10 NTU)

Dependent on water temperature

Membrane Process Units

To meet peak demands, the Sweetwater treatment facility has been designated to produce 8.0 MGD (30.28 MLD) with a feed water temperature of $\geq$60°F (15.6 °C).

Since Sweetwater has groundwater available to supplement surface water sources, the TCEQ has accepted reduced permeate production when using colder waters.

Secondary Water Recovery

Rationale for selection

Limited available supplies
& Expensive Development Costs

For a municipality to connect to an existing raw water source, costs from $1.0 to $2.0 million per 1 MGD of supply capacity are not uncommon.

The resulting design allows for waste feed (10%) from the primary UF membrane process units to be pumped into a secondary UF membrane process unit.

At 90% recovery from the secondary UF membrane system, an overall plant recovery of 99% will be achieved.

Secondary Water Recovery

The high solids in the secondary recovery process unit reduces the net design flux to 14 gfd.

Sweetwater saved a potential $720,000 to $1,400,00 in raw water development costs with the increase in total recovery at the WTP from 90% to 99%.

The volume of waste water drops from 800,000 GPD (8 MGD production capacity at 90% recovery) to 80,000 GPD (8 MGD production capacity at 99% recovery).

Conclusions

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The pilot study conducted for Sweetwater established design parameters for a full-scale enhanced coagulation, UF membrane surface water treatment plant.

Enhanced coagulation combined with UF membrane technology will allow Sweetwater to meet TOC reduction and turbidity/particulate removal standards.

A membrane module, or element, is the basic building block of the immersed system. Typically, these are manifolded to comprise a group of modules named a "cassette." Each cassette is connected to a common permeate header (typically 1 per process train) operated under a vacuum. The appropriate number of modules, cassettes and process trains for a facility is determined based on the feed water quality, treated and reject water requirements and redundancy considerations.

Conclusion-Costs

Summary of Construction Costs

	Costs
General Plant Construction Contract	$6,219,500
0.82 Million Gallon Welded Steel Clearwell	$495,500
ZENON Immersed UF Membrane System	$3,047,500
TOTAL CONSTRUCTION COSTS	$9,762,500

8.0 MGD (expandable to 10.0 MGD) by adding membrane cassettes to the process tanks.

Conclusion-TCEQ Approval

TCEQ granted full credit (3-log) for Giardia removal due to the UF membrane's "physical barrier"

TCEQ granted a 1-log credit for removal/inactivation of viruses due to the enhanced coagulation operation mode

Disinfection protocol includes the application of chlorine dioxide to the raw water and the post-membrane development of chloramines to achieve the remaining 3-log virus removal/inactivation required under the Surface Water Treatment Rules

Conclusion-99% Recovery Operation

Reject (10%) from the primary UF membrane process tanks will be pumped into a single, secondary UF membrane process tank.

With the secondary UF membrane system operating at a 90% recovery, the waste stream discharged from the facility will be 1% of the feed water.

Conclusion - A "First"

The Sweetwater Treatment Plant will be the first immersed, vacuum-driven membrane system in Texas operating with enhanced coagulation and achieving a 99% recovery of feed water.